Transformation of degraded forests into semi-natural production forests in northern Thailand

Inaugural Dissertation
Faculty of Forestry
Albert-Ludwigs-University

Freiburg im Breisgau, Germany

submitted by

Timm Tennigkeit
born in Darmstadt

Freiburg im Breisgau 2000

ABSTRACT

Key words: Thailand; tropical deciduous forests; degraded; site index; improvement treatments; semi-natural production forest.

This study focussed on the degraded Deciduous Dipterocarp-Oak Forests (DDF) in northern Thailand. The aim was to provide information on site and stand conditions and to propose and assess improvement treatments to transform these forests into semi-natural production forests.

As a consequence of extensive exploitation and dramatic loss of forest cover, Thailand declared a nationwide logging ban in 1989. To halt ongoing forest destruction, by increasing the forest utilisation value, degraded forests have to be transformed into productive forests.

The site research showed that the observed DDF on some sites originated from more productive forest types. For the first time, site productivity could be measured by stem section analyses on *Vitex limoniifolia.*

In the research stands, stocking volume was low but the number of stems was high. Only few stems of large dimensions occurred and many of these were damaged. Regeneration seemed sufficient for transformation into semi-natural production forests.

Based on the observed site productivity and stand conditions, improvement treatments were proposed and applied for this transformation. The economic feasibility of this approach was assessed: gross margins would be negative initially, however positive gross margins can be achieved in the future if timber of larger dimensions can be extracted.

Taken together, the transformation of degraded DDF into semi-natural production forest as proposed and tested, proves to be a promising approach for forest protection by utilisation.

ACKNOWLEDGEMENTS

This study was conducted between November 1997 and March 2000, as part of the European-Thai-Forest-Project (ETFP) "Ecology and Sustainable Semi-Natural Silvicultural Management of Indigenous Forests in Continental Southeast Asia" (1994-1999), funded by the European Union. Additional funding was provided by a research fellowship of the State Baden-Württemberg (Landesgraduiertenförderung) and by the German Academic Exchange Service (Deutscher Akademischer Austauschdienst).

First of all, I would like to thank my supervisor Prof. Dr. Jürgen Huss, Chair of the Silviculture-Institute and coordinator of the ETFP, for his guidance and enthusiasm for the research in Thailand and at the Institute in Freiburg.

Above all I would like to thank:

- Dr. Clemens Fehr for his support and assistance in Thailand, in dealing with the project administration in Freiburg and for valuable discussions and revisions of this thesis;
- Dr. Horst Weyerhäuser for organisation of this research, providing contacts in Thailand and for valuable discussions and comments on this thesis;
- My brother, Dr. Frank Tennigkeit for his encouragement during the final stages of this thesis and for valuable discussions and revisions.

In Thailand, the study was supported by many friends and colleagues. Dr. Viroj Pimmannrojnagool, Director at the Royal Forest Department in Thailand, who provided continual assistance throughout the project. My friend Somchai Noangnuang, Head of the Silviculture Research Station No. 1 at Huai Som and his wife, for his courage and field support. John F. Maxwell for his invaluable taxonomic knowledge and help with species identification, as well as Dr. Stephen Elliott for helpful discussions.

At Freiburg University, I appreciate the support of Prof. Dr. Heinrich Spiecker, Chair of the Institute of Forest Growth, Dr. Hans-Peter Kahle and Clemens Koch for providing assistance with stem disc preparation and analysis.

I also would like to thank Philippa Allen for proof reading and Nele Rogiers for the final formatting, as well as many colleagues at the forest faculty and my family for their support.

ABBREVIATIONS

Study site abbreviations

HR	Huai Rai (main research area)
HS	Huai Som (main research area)
PC	Pa Cha Lua (research location used for site studies only)
MN	Mae Naa Baa (research location used for site studies only)
HKK	Huai Kha Kaeng, west Thailand, a relatively undisturbed forest - mentioned several times for comparison with the degraded forests investigated

Other abbreviations used within the study

CSEA	Continental Southeast Asia
DBH	Diameter at Breast Height
DDF	Deciduous Dipterocarp-Oak Forests
ETFP	European-Thai-Forest-Project
F-trees	Future tree or potential crop tree
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
MDF	Mixed Deciduous Forest
NTFP	Non Timber Forest Products
PCA	Principal Component Analysis
RFD	Royal Forest Department
NODDF	Not in DDF
NOI	No indicator value

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1 GENERAL INTRODUCTION AND PROBLEM STATEMENT

1.1 GENERAL INTRODUCTION

In continental Southeast Asia (CSEA, Fig. 1.1), the forest covers approximately 70 million hectare or 36 % of the total land area. Uncontrolled forest exploitation, agricultural expansion and urban development are the major threats to the remaining forests. In the less developed countries, Cambodia, Laos and Myanmar, between 40 and 55 % of the total land area is still covered by forests, while in Vietnam and Thailand only 28 % and 23 % respectively of land is under forest cover (FAO, 1999).

Fig. 1.1: Map of continental Southeast Asia (source: WORLD RESOURCE INSTITUTE).

Thailand has one of the highest deforestation rates in the World, according to the latest World resource assessment in 1995 (FAO, 1999), creating a wide range of ecological problems. Annual deforestation rate was estimated at 2.6 % between 1990 and 1995 despite a nationwide logging ban introduced in 1989. The future shortage of water may well be the most crucial problem, particularly if uncontrolled logging persists in the head watersheds and mountain areas. In addition to the disappearance of large forests, other areas were spatially and temporarily disturbed.

These different degrees of forest disturbance have led to a major loss of forest productivity. In the Asia Pacific region, the demand for forest products and timber will increase significantly with the growing population and regional economic growth (FAO, 1998). To meet this demand, the Asia Pacific region already contains three-quarters of the

World's tropical plantation area (FAO, 1998). However, due to social and economic problems these areas can not be extended to fulfil the increasing wood demand alone (CARRERE & LOHMANN, 1997). Thus, timber prices will rise in the future (ITTO cited after FAO, 1998).

In the future, forest resources will be managed in one of three ways. Approximately 10 % of the forest cover in tropical Asia will be totally protected for conservation purposes, the same amount will be managed intensively as forest plantations. On the remaining 80 %, forest functions might not be segregated, rather forests will serve as a multifunctional system, producing non-timber and timber products, protecting water resources and, with rising prosperity, will serve for recreational purposes.

Presently, most of the forest area available for timber production in tropical Asia is degraded and only a fraction of these forests are actively managed (FAO, 1998). To utilise this neglected potential, forest productivity in degraded forests has to be increased (WIPPEL et al., 1997).

This study investigates the transformation of degraded, Deciduous Dipterocarp-Oak Forests (DDF) in northern Thailand into semi-natural production forests.

1.2 STATE OF THE WORLD'S TROPICAL DECIDUOUS FORESTS

Tropical deciduous forests, also referred to as tropical dry forests or seasonal tropical dry forests (BULLOCK et al., 1995), cover approximately 55 % of the total tropical forest area in Thailand (see Tab. 1.1). In contrast to tropical rainforests, deciduous forests received relatively little scientific and political attention. Degradation and conversion of these forests are far more advanced (BULLOCK et al., 1995; RUNDEL & BOONPRAGOB, 1995; BMELF, 1997).

Tab. 1.1: Area of Forest formations by region (RFD, 1992; FAO, 1993).

Forest* formation	Total tropics		CSEA		Thailand	
	Million ha	%	Million ha	%	Million ha	%
Evergreen forests	920	42	35	46	6	45
Deciduous forests	840	48	40	54	7	55
Total tropical forest	**1,760**	**100**	**75**	**100**	**13**	**100**

*Forests, according to the FAO (1999) definition, are an ecosystem with a minimum of 10 % crown cover of trees and/or bamboo, generally associated with wild flora and fauna and natural soil conditions, and not subjected to agricultural practices.

The FAO (1996) characteristics of tropical deciduous forest are presented in Tab. 1.2. The denomination of the forest formations is derived from the UNESCO (1973) classification. The dominant forest formations of this forest type are moist semi-deciduous, deciduous forest woodlands and tree savannahs.

Mean annual rainfall	mm y^{-1}	1000-2000
No. of rainy days	days y^{-1}	70-170
Length of the dry season	month	2-7
Mean annual temperature	°C	22-27
Mean temperature of the coldest month	°C	> 23

Tab. 1.2: Bioclimatic parameters of tropical deciduous forests (FAO, 1996).

1.3 SECONDARY AND DEGRADED TROPICAL DECIDUOUS FORESTS

Disturbed forests can be divided into two categories, secondary and degraded forests:

- **Secondary tropical forests** develop where previous forest vegetation has been destroyed (RICHARDS, 1955; SIPS 1993).
- **Degraded tropical forests** are characterised by their decrease of canopy cover density (FAO, 1996), originating from selective felling (SIPS, 1993). The major threat for these forests, besides logging, are fires (BLASCO, 1983). Globally, about one third of all deciduous forests are threatened by annual forest fires (GOLDAMMER, 1993; JONES, 1997).

The global amount of degraded and secondary tropical deciduous forests is unknown. The reasons for this lack of information is the difficulty in setting reference points and to define valid inventory criteria on a regional and worldwide level. The forest assessment of the FAO (1993, 1996) provides figures on the changes in forest cover between 1980 and 1990 (see Tab. 1.1). These figures probably underestimate the amount of deforestation and degradation (JEPMA, 1995). In the observed decade, approximately 10 % of all tropical deciduous forests were disturbed, whereas only less than 5 % of the other forest types suffered the same fate (FAO, 1996). In comparison with other continents, change in forest cover is most dramatic in Asia (14 %).

Tab. 1.1: Types of forest cover changes by region between 1980 and 1990 in tropical deciduous forests.

Region	**Tropical deciduous forest cover**	**Total change in forest cover (1980-1990)**		**Deforested***		**Degraded, or fragmented****	
	Million ha	Million ha	%	Million ha	%	Million ha	%
Latin America	360	34	9	30	88	4	12
Africa	310	29	9	16	55	13	45
Asia	100	14	14	8	57	6	43
Total tropics	770	77	10	54	70	23	30

*Deforested, total loss of forest cover

**Degraded or fragmented, decrease of canopy cover density or partial deforestation

The types of change in forest cover differ from continent to continent. In **Latin America** 88 % were converted into non forest cover, while the amount of degraded forest just increased by 12 %. In **Asia** and **Africa,** forest conversion and degradation are approximately balanced.

Why is forest disturbance particularly severe in deciduous forests?

Deciduous forests are considered as one of the most endangered major tropical ecosystems (JANZEN, 1986). First of all, fire susceptibility during the dry season allows more rapid exploitation and conversion of these forests when compared to evergreen forests (GOLDAMMER, 1993). In the tropics, human settlements occur in areas of deciduous forests because of the more favourable climate. As expected, there is a positive correlation between the degree of forest disturbance and population density, while an inverse logarithmic relationship is observed between population density and the proportion of forested land (BULLOCK et al., 1995).

The outlook for forests in the next decade is rather pessimistic. More natural forests will be degraded or converted to other land uses, although the rate of conversion is likely to decrease (FAO, 1998), while policy support and private incentives to improve disturbed forests increase only slowly. As long as timber can be extracted at low costs from forest exploitation, there is no incentive to improve the productivity of disturbed forests. However, in the long run, the production potential of this presently neglected resources will be utilised.

1.4 SIGNIFICANCE OF DECIDUOUS DIPTEROCARP-OAK FOREST IN CONTINENTAL SOUTHEAST ASIA

For CSEA the Deciduous Dipterocarp-Oak Forest (DDF) is a typical example for such a resource. Named differently, Dry Dipterocarp-Forest in western Thailand, Indaing forest in Myanmar, and Foret Claire in Laos, Vietnam and Cambodia, this forest type occurs everywhere in CSEA.

In Cambodia it dominates 40 % of the forest cover (BLASCO, 1983), in Thailand approximately 32 % (RFD, 1992), while in Laos and Vietnam 10 % and 14% respectively is covered by this forest type (FAO, 1981). All over CSEA this forest is over-utilised and severely degraded by short interval ground fires (BLASCO, 1983; GOLDAMMER, 1993).

This forest type is regarded as unproductive and until recently, attracted low public and institutional interest. However in light of resource scarcity in the developing CSEA countries, the question arises of how productivity of this forest type can be increased. Limited information is available on its productivity potential and scant research has been completed to address the potential to improve forest productivity.

1.5 FORESTRY IN THAILAND

1.5.1 General socio-economic characterisation

Thailand is located in the centre of CSEA (area 513,000 km^2) and is by far the most developed country within the region. The last two decades have seen a rapid industrialisation and economic growth mainly in southern and central Thailand (Bangkok). However in rural areas, for example northern Thailand, agriculture predominates. The following parameters, taken from BARRATA (1996), describe the socio-economic background of the country (Tab. 1.1).

Officially a timber based forest economy outside forest plantations is non-existent, due to a nationwide logging ban since 1989. However illegal subsistence forest utilisation plays a major economic role in northern Thailand.

Tab. 1.1: Socio economic information on Thailand and Germany for comparison (BARATTA, 1996; FAO, 1999).

Socio-economic parameters		Thailand	Germany
Inhabitants	Mill./inh.	60	80
Inhabitants living in rural areas	%	80	13
Inhabitants living in Bangkok/Berlin	Mill./inh.	5.5	3.5
Gross domestic product (GDP/inhabitant) in 1995	US$	2,750	27,500
Gross domestic product development in 1995	%	8.5	3
Contribution of the different sectors to the GDP			
Agriculture	%	10	<1
Industry	%	40	35
Service	%	50	64
Employees by sector			
Agriculture	%	57	3
Industry	%	18	36
Service	%	25	61

1.5.2 Forest types in Thailand

The forest types in Thailand can be divided into deciduous and evergreen forests (Tab. 1.1). Deciduous forests, as presented cover an area of approximately 55 % of the total forest cover. Evergreen forests including minority forest types cover 45 % of the total forest cover throughout the country.

Forest type	Proportion of forest cover %
Tropical deciduous forest	**55**
Deciduous Dipterocarp-Oak Forest	32
Mixed Deciduous Forest	23
Tropical evergreen forest	**45**
Minority forest types	
Forests with pine	1.5
Mangrove forest	1.5
Shrub forest	< 1

Tab. 1.1: Distribution of forest types in Thailand (RFD, 1992).

Deciduous forests are found in areas with medium to low rainfall, pronounced dry seasons and soils of poor water holding capacity. They can become partly or wholly deciduous (SMITINAND, 1992). The term Deciduous Dipterocarp-Oak Forest is used to indicate that Dipterocarp species and Oak are the characteristic species of this forest type in northern Thailand. It is the most widely distributed forest type in Thailand, occurring on more than 30 % of the total forest cover (DHANMANONDA, 1988). This forest will be described in detail in Chapter 3.

The second deciduous forest type, the Mixed Deciduous Forest (MDF) is characterised by heterogeneous species composition and structure. Except in those rare forests, where Teak still exists, no species receives a pronounced dominance (SMITINAND, 1992).

Today, **evergreen forests** in Thailand occur in the mountain areas as well as in Thailand's southern peninsula, where annual rainfall can exceed 2,000 mm. Some authors defined these evergreen forests in Thailand's peninsula as tropical rain forests (SMITINAND, 1992), regardless of the monsoon induced dry season that can last up to two months.

Among the **minority forest types**, forests containing pine were exploited quite heavily in the past (WERNER, 1993). Pine trees (*P. kesiya* and *P. merkusii*) are always the first trees extracted, due to their high timber value. Of the two pine species, *P. kesiya* is far more common and occurs on a wider range of altitudes (MAXWELL et al., 1995). Mangrove forests can be found near the sea at the west coast around Ranong and at the Gulf of Thailand (SMITINAND, 1992), where the forest is periodically inundated. Shrub forests grow under very poor soil conditions, often under high saline conditions.

1.5.3 Forest utilisation in Thailand

In the 19th Century, forests became increasingly important due to their economic value. Ownership disputes between local feudal lords began to emerge. The central government in Bangkok intervened and finally gained control over the lucrative timber trade and the political administration of remote provinces. Following the Royal Thai Forest Department establishment in 1896, forests were declared state property and utilisation became state-concessioned.

As forest management system, a modified Brandis (Selection) System originally invented for the management of Teak forests, was applied for evergreen and other mixed deciduous forest types in Thailand (BOONYOBHAS, 1961; BANIJBATANA, 1962a,b). In felling cycles of 30 years, 80 % of all trees above a species specific girth limit (60 cm for Teak), were girdled to dry out and felled two years later. A fifth of the trees were left as seed bearers (BOONYOBHAS, 1961). However, timber sustainability was not achieved, as the proposed felling intensity was too high (LÖTSCH, 1958). Timber management in DDF was even less planned. Aside from railway sleepers and construction timber, mainly fuel-wood was produced.

After 1945, all Thai forests were heavily exploited by international concessionaires (POFFENBERGER et al., 1990). Mandatory management regulations were not always followed: illegal felling, as investigated from stump inventories, exceeded legal felling by 150 % (LÖTSCH, 1958). These practices lasted until the forests disappeared and a logging ban was declared in 1989. For forest protection, the Thai Government revoked all logging concessions except from those in mangrove forests and forest plantations.

The loss of forest cover in Thailand is shown in Fig. 1.1. Between 1961 and 1991, the forest cover dropped by 50 % (RFD, 1992). The official estimate of 23 % forest cover in 1993 (FAO, 1999) is considered too high by others, which estimated that only 15 % of forest coverage remained (RIGG, 1993).

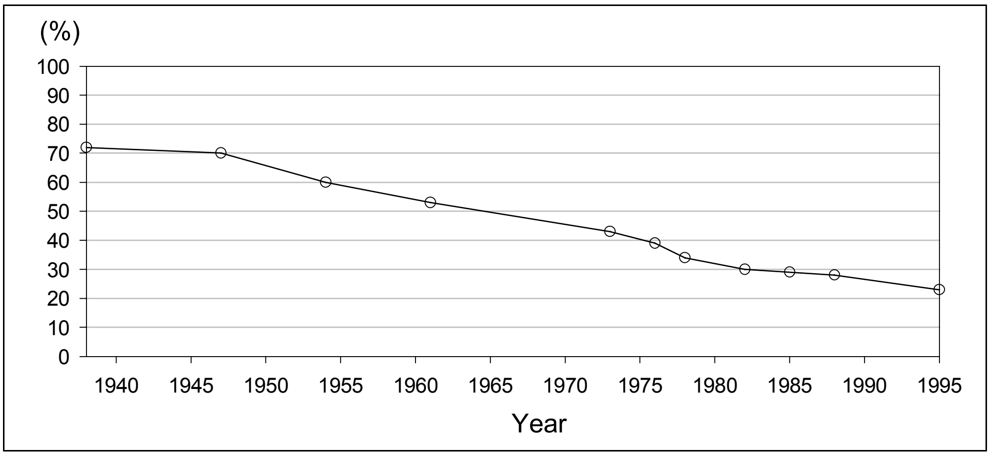

Fig. 1.1: Loss of forest cover in Thailand between 1938 and 1995, related to total land area in % (THAILAND DEVELOPMENT RESEARCH INSTITUTE, 1988; FAO, 1999).

The forest distribution by region (Tab. 1.1) is highly related to topography and population growth. The plains were the earliest areas to be converted to agriculture, while along the mountain ridges in northern Thailand and in remote parts of western Thailand, the forest remained relatively intact until 1945. Most of the existing forests and major watersheds remain in northern Thailand.

Region	Forest cover %
North	56
North-east	16
East	6
South	10
Central and west	12

Tab. 1.1: Thailand forest cover by region (RFD, 1997).

Today in Thailand, forests remain on sites with poor conditions, are predominantly degraded and unproductive. To increase forest cover and produce timber, two possibilities exist: 1. Forest plantations or 2. Transformation of degraded forests into semi-natural production forests.

1.5.4 Forest Plantations

Large scale forest plantations have been established in Thailand, starting as early as 1906 (KAOSA-ARD, 1995), to cover losses of naturally grown teak forests. At the beginning of this era teak was the favourable species for forest plantations. Later, fast growing *Eucalyptus* plantations were set up by the pulp and paper industry. Today, only 25 % of the forest plantation area in Thailand is stocked with teak (see Tab. 1.1).

Tab. 1.1: Total forest plantation and teak plantation cover in selected tropical Asian countries (KAOSA-ARD, 1995; DUPUY, 1995; FAO, 1997).

Country	Total forest plantations	Teak plantations	
	Million ha	Million ha	%
India	14.5	1.5	10
Indonesia	6.0	1.0	16
Viet Nam	1.5	< 0.01	< 0.1
Thailand	0.5	0.13	25
Total	22.5	3	5

Displayed are tropical Asian countries with more than 0.5 million ha forest plantations.

In terms of investment, afforestation requires between US$ 650 and US$ 850 per hectare compared to US$ 150 per ha for rehabilitation of degraded forests (FAO, 1998). Additionally, some plantations suffer from lack of silvicultural management and poor seed supply. Yield and timber quality of plantations on marginal sites are generally poor (SAHUNALU, 1992). Optimistic expectations from private and public investors were rarely reached. Therefore, at present, there is a decreasing interest to invest in forest plantations in Thailand. In addition, plantations on favourable sites compete with agricultural use. The political resistance against forest plantations therefore increases, as forest plantations, subsidised by international and national investors, are regarded as socially and ecologically unacceptable (CARRERE & LOHMANN, 1996).

In conclusion, area suitable and available for forest plantations is very limited in Thailand. Thus, it can be not expected that forest plantations will significantly increase to cover the timber and fuel-wood demand.

1.5.5 Transformation of degraded forests into semi-natural production forests

The majority of forest cover on marginal sites in Thailand is DDF (KUTINTARA, 1975), thus not suitable for profitable forest plantations (see above). In addition, most of DDF is degraded and requires improvement. A transformation into semi-natural production forests seems the only possibility.

Semi-natural production forests have emerged as a compromise between total conservation and optimised timber production of indigenous forests. This approach relies on indigenous tree species. Natural forest structures and self-regeneration are favoured. However, to match ecological conditions with production objectives, species composition and stand structure may be modified. Special attention is usually given to individuals of valuable timber species that are vigorous and of good stem quality, but also to ecological valuable minority species (HUSS & SUTISNA, 1993).

Such forests provide some conservation, allow additional income from non-timber forest products (NTFP) and are socially adapted, if supported by the local communities.

1.5.6 Community forest management

Officially, 48 % of the total land area in Thailand is declared as forest, which is under the administration of the Royal Forest Department. However, approximately only one third is covered by forest in a real sense (LOHMANN, 1983). The other two thirds are inhabited by

8-15 million people in about 150,000 villages. Most settlements do not benefit from secure land titles and land-use rights (BRENNER et al., 1998).

Community forestry as part of Thailand's National Forestry Policy was proposed in a cabinet resolution in 1985. Since then, a community forest bill is under discussion, but has not passed Parliament. The main issues concern property rights and forest management responsibilities (BRENNER et al., 1998). Another unresolved question is whether conservation and production functions of forests should be spatially segregated or integrated.

Very simplified, social interest groups represent the interests of the people living from forests. On the other hand, conservationists and the majority of the Royal Forest Department are more concerned about issues related to the state of the forest as a source of biodiversity, tourist attraction and future income from timber extraction.

In conclusion, most parties agree that community forests should be established, to give communities control and responsibility of forest utilisation. The demand for sustainable management (definition see Appendix 10) of these forests still remains. Also it is recognised that there is a severe lack of basic forest inventory data and technical management experience to make informed decisions on optimal forest management.

1.5.7 Review of forest and silvicultural research

Systematic research on ecology and silviculture of natural forests in Thailand began with the forest inventory conducted by the FAO (LÖTSCH, 1958). It predicted a collapse of forestry if management practices were not fundamentally altered and systematically research based. Thereafter, the forest faculty that was founded in 1936 at Kasetsart University in Bangkok initiated basic forestry research.

Initially, research focussed on forest descriptions (OGAWA, 1961; RFD, 1962; SUKWONG, 1974, 1982; KUTINTARA, 1975; SMITINAND, 1977; KHEMNARK, 1978; BANGKURPOL, 1979) and biomass assessments (NEAL, 1967; SABHASHRI, 1967; KUTINTARA, 1975; WANUSSAKUL, 1989). The work of NEAL and SABHASHRI served military-forensic purposes, WANUSSAKUL described seasonal biomass pattern.

The phenology of individual species, for example the xerophilous *Dipterocarpaceae* have been described (SMITINAND, 1980). A general account of phenological observations in deciduous lowland forests was provided by SUKWONG (1974), SUKWONG & DHAMANITAYAKUL (1977). The phenology of deciduous forest in the northern hills was described by ELLIOTT et al. (1994).

Functional aspects were approached only in recent years, with a strong focus on fire ecology. Effects of increased fire frequency and the detrimental impact it has on regeneration and survival of deciduous forests was investigated (SUKWONG et al., 1975; STOTT, 1976; 1984, 1986, 1988 and 1990; SATHIRASILAPIN, 1987; SUNYAARCH, 1989; SUTTHIVANITCH, 1989; KETUPRANEET et al., 1991; KANJANAVANIT, 1992; POKAEW et al., 1994; KAFLE, 1997; TENNIGKEIT, 1997).

Space re-occupation in DDF is completed three to four years after a logging event, predominantly because of the prolific resprouting capacity of the xerophytic species involved (THUAMSANG, 1983). Canopy gaps in DDF are characterised by increased light availability on the ground; there exists no gap-specific regeneration-type. This was attributed to the extreme effect of site-conditions, allowing only the most vital species to survive (DHANMANONDA 1988, 1992, and 1995).

Composition and population structure of DDF was found to depend on elevation, slope, exchangeable calcium and other environmental gradients (BUNYAVEJCHEWIN, 1983a,b and 1985). Similarly, the occurrence of transitional deciduous community-types were related to environmental gradients by BLASCO (1983) and THITATUMMAKUL (1985).

1.5.8 Research and management targets in Thailand

In conclusion, early research focussed on controlled natural forest utilisation and management practices (LÖTSCH, 1958; BOONYABHAS, 1961). These proposals were sound and made correct predictions, however social and economic circumstances prevented their implementation. Later, mostly ecological mechanisms were investigated. Today, with much forest cover lost and most remaining forests degraded, research has to focus on transformation of degraded forests into semi-natural production forests to prevent ecological catastrophes and provide economic benefits.

Forest management targets in Thailand were set by the Thai-Forestry-Master Plan Team (1993). The main goals comprise:

- increase of forested land to 40 %;
- conservation of existing forests;
- improved management of reforested areas and degraded forests;
- self-sufficiency for most forest products;
- rehabilitation of the main watersheds in the North;
- increased involvement of the public in forest planning and management.

Unfortunately, no progress towards the above goals has been made to date.

While these goals are ambitious and require substantial political, social and economical inputs, the transformation of degraded forests into semi-natural production forests seems reasonable provided comprehensive forest inventory data and technical management expertise are available.

1.6 RESEARCH OBJECTIVES AND STRUCTURE

1.6.1 Research framework, objectives

This study was conducted within the frame work of the **European-Thai-Forest-Project** (ETFP, 1994 - 1999). The overall aim of the ETFP was to identify the ecological basis, means and methods for semi-natural silviculture in degraded deciduous forests in Thailand (FEHR et al., 1999).

The project consisted of two parts. The **first part of the project** included the study of species composition, structure, increment and regeneration dynamics in relatively undisturbed deciduous forest formations (FEHR, 1998; WEYERHÄUSER, 1998). This provided the necessary background for subsequent research. As "the most significant area of intact, relatively undisturbed deciduous forest" in Thailand (SMITINAND, 1989) the Huai Kha Kaeng Wildlife Sanctuary in west Thailand provided an adequate research site.

The main objective of the **second part of the project** was to study degraded DDF and to provide treatment proposals to transform these forests into semi-natural production forests.

To this end, research sites in northern Thailand where chosen, where this forest type is frequently encountered.

1.6.2 Structure of the study

The introduction (**Chapter 1**), provided information on forestry in Thailand, the aims of this study and the relevant background data pertaining to the project.

Site studies (**Chapter 2)** characterise different DDF site quality and productivity conditions. Site delineation approaches based on vegetation and soil parameters are tested. These indirect approaches to assess site productivity are compared with direct site productivity measures, based on height growth reconstruction.

Stand studies (**Chapter 3**) describe stand condition and utilisation at two research areas. Based on this information, silvicultural treatments (**Chapter 4**) of different regimes are developed and applied on an experimental scale. Stand improvement treatments for community based forest management are investigated as well. Finally, the projected economic revenues from these treatments are assessed.

General discussion and conclusions (**Chapter 5**) are integrating previous chapters and discussing perspectives to establish semi-natural production forests.

2 SITE QUALITY AND PRODUCTIVITY ASSESSMENTS

2.1 INTRODUCTION

Site quality can be characterised by soil and vegetation analyses, while site productivity is usually estimated from site index studies. These site aspects will be addressed in this chapter.

Based on the literature, current methods of site quality and productivity measurements are reviewed and applied to differentiate site quality levels. These are then compared with the respective productivity estimates.

In northern Thailand, as elsewhere, early forest research focussed on classifying forest types and sites. The investigation of site quality was only a minor objective. The major concern was to find new species and devise a forest classification system. These early surveys were very valuable because they described the natural range the forest types once occupied.

The German botanist Hosseus conducted the first floristic inventory of northern Thailand (HOSSEUS, 1911). Classifications of forest types in Thailand based on species composition have been proposed by MAHAPOL (1954), CREDNER (1935), OGAWA et al. (1961) and KÜCHLER & SAWYER (1967). Classifications specific to northern Thailand were published by SANTISUK (1988) and MAXWELL et al. (1995). The focus of these studies was on qualitative plant sociology. Based on multiple regression analysis, site conditions and their relation to DDF species composition was investigated (KUTINTARA, 1975; BUNYAVEJCHEWIN, 1983a). Studies on site productivity based on growth monitoring data were only conducted on forest plantations (SAHUNALU et al., 1992). Only recently quantitative plant ecological and multivariate vegetation analysis methods were applied to classify vegetation patterns (FEHR, 1998).

The development of a DDF site classification based on site index is of major importance for the selection of sites where future silvicultural improvement treatments can be expected to have optimal impact.

2.2 RESEARCH OUTLINE

The study sites were at Huai Rai (HR) and Huai Som (HS) as these sites also contained the silvicultural improvement treatments. To investigate different site conditions, additional study sites at Pa Cha Lua (PC) and Mae Naa Baa (MN) were chosen. Data from previously studied research sites at Huai Kha Kaeng, west Thailand by TENNIGKEIT (1997), FEHR (1998) and WEYERHÄUSER (1998) were also used.

The following research steps can be differentiated:

- In the first stage, different soil parameters were measured. Based on these soil data, sites were clustered.
- In a second stage, the vegetation was analysed and compared between research sites.
- Finally, site productivity was estimated based on site index studies on *Vitex limoniifolia.*

2.3 REVIEW

The review describes general soil and non tree species vegetation features related to DDF. Basic information on site index development and growth reconstruction on tropical trees are provided.

2.3.1 Soil and geographic features

Elevation and soil conditions are the key factors determining the natural distribution of DDF (BLASCO, 1983). DDF occurs from sea level up to 1,300 m a.s.l. (BUNYAVEJCHEWIN, 1983b), mostly up to 900 m a.s.l. (ELLIOTT, et al., 1989; BANGKURDPOL, 1979).

DDF is restricted to poor and shallow soils (SMITINAND, 1992; BANGKURDPOL, 1979), where competition with tree species of other forest types is low. In most cases soils do not exceed 50 cm depth. Often soils are also highly eroded, without recognisable profiles (BLASCO, 1983). The pH varies between 4.5 and 6.5. The texture of the top horizon can be sandy to sandy clay, the proportion of clay is increasing with soil depth (BIOTROP, 1976, 1977). The nutrient status is low and the soil organic matter amounts to only 2-4 % of the top soil substance (SANGTONGPRAOW & DHAMANONDA, 1973; KAFLE, 1997).

2.3.2 Bioclimatic zone

DDF occurs in the tropical monsoon zone (RUNDEL & BOONPRAGOB, 1995), where annual rainfall ranges from 1,000 to 1,500 mm. Rainfall distribution is bimodal, with four to seven dry months (BLASCO, 1983). Evaporation exceeds precipitation for up to nine months (STOTT, 1990).

2.3.3 Vegetation

Among the dry season non tree flora, grass communities remain virtually the same in different types of deciduous forests, open woodlands and savannahs of Southeast Asia (BLASCO, 1983). *Themeda triandra* is one species belonging to this cosmopolitan grass community typical for DDF. Other cosmopolitan grasses, like *Allopteropsis semialata, Eulalia tristachya, Heteropogon triticeus, Sehima nervosum* are quite common in Thailand.

The dwarf palm *Phoenix humilis* is characteristic of DDF (STOTT, 1988; BLASCO, 1983). *Arundinaria pusilla* is a dwarf bamboo frequently occurring in DDF (SUKWONG et al., 1975; KUTINTARA et al., 1977; BLASCO, 1983; SMITINAND, 1992; RUNDEL & BOONPRAGOB, 1995). *Memecylon edule,* originates in DDF. It rarely occurs in other forest types (BLASCO, 1983a). Very few woody climbers occur in the forests, but *Spatholobus parviflorus*, *Aganosma marginata* and *Celastrus paniculatus* can be found.

Although the ground flora of DDF tends to be quite similar to MDF, dense bamboo thickets of *Dendrocalamus membranaceus, D. nudus* and *Bambusa tulda* are characteristic for MDF. Similarly, only a few trees occur exclusively in DDF (ELLIOTT & MAXWELL, 1998). Tree species composition of DDF will be described in Chapter 3.3.1.2.

2.3.4 Construction of site index curves based on tree ring investigations

Site productivity assessments in this context aimed to predict stand growth or biomass production and, subsequently, sustainable harvesting quantities. At the end of the 18th Century, preliminary studies on the relation between site productivity and forest growth were initiated. From this the first site index tables were developed (MÜLLER, 1915). For a comprehensive review of the different methods to determine site productivity refer to UNTHEIM (1996) in temperate forests and VANCLAY (1992) for tropical moist forests.

In temperate forests, the relationship between stand age and tree height is used as a site index. Site productivity is expressed as a function of volume production and age.

In contrast to temperate conditions, in the tropics few site quality delineation techniques exist. The most common technique is to model the relationship between forest growth and site parameters (VANCLAY, 1992).

Two main modelling approaches prevail: priori and posteriori models. Priori models are based on a set of assumptions while posteriori models rely on empirical data fitted to multiple regressions (KAHN, 1994). Posteriori models require permanent sample plots to correlate tree growth data to measurable site parameters (climate, soil, vegetation). In the tropics such information is rarely available.

Until recently, site index assessments received little attention in the tropics. Thus the techniques reviewed to construct site index tables refer to research conducted in temperate forests. Historically, site index was defined as the height of the dominant stand at a specified reference age (CURTIS, 1964). A more recent approach is to consider not only a single height at a particular age but also to consider the overall shape of the height growth curves (MCDILL & AMATEIS, 1992). This approach requires information on the maximum tree height. Since this is often unknown in the tropics, the method is rarely applied.

Site index assessments based on growth monitoring or stem analyses of trees grown in even-aged stands is common (MONSERUD, 1984). For cross-section analysis of growth monitoring data stands of different age are sampled systematically and merged into a combined growth series. They were also called false growth series because growth information did not correspond to a single stand.

A serious limitation of this method is the assumption that sampling occurs with the same sampling intensity in the different age-classes (MONSERUD, 1984). Another shortcoming of this approach is the bias in site selection for site index development: care is taken to encompass the range of sites prevailing, thus the outcome of the study is already reflected in the pre-stratification of the study sites.

Of the two methods, stem analyses usually results in more realistic assessments of potential site productivity (CURTIS, 1964; MONSERUD, 1984; BIGING, 1985).

2.3.4.1 Selecting trees for stem analyses

For stem analyses a certain amount of trees have to be cut and sectioned, in order to determine height growth between these different intersections by analysing tree ring differences (see Chapter 2.4.4.3).

Fearing that competition and suppression would affect growth development, only trees without any previous height growth suppression were selected for stem analyses-based construction of site index curves. It was usually only applied in managed and even-aged stands (CURTIS, 1964; CARMEAN, 1972; ABETZ, 1985; UNTHEIM, 1996).

If applied in uneven-aged and mixed stands, it was considered important to select trees of dominant position. However, no differences were found in the height growth of dominant site trees in even aged and uneven-aged stands (MONSERUD, 1984). This can be explained by the low sensitivity of the height growth of dominant trees to natural competition and/or silvicultural treatments (PRETZSCH, 1992; ONYEKWELU & FUWAPE, 1998; HERRERA, 1999). In contrast, diameter growth is strongly affected by competition, it reveals information on previous suppression (MONSERUD, 1984; BIGING, 1985).

The live crown ratio, which describes the proportion of living crown length to total tree height is another indicator of the past social position and competitive relationship of a tree within the stand. With increasing competition, the crown diameter increment is reduced. Shading will cause lower branches to die. Trees assuming dominant positions will continue to expand their crowns. However, the live crown ratio will be relatively short. In addition, the tree height/diameter ratio is a strong indicator of the available growing space a tree had in the past (SMITH et al., 1997).

Sample size and accuracy are inversely related. The accuracy of a site index curve can be estimated by comparing the variance of individual tree and the mean stand development on a given site or alternatively by comparing the error of a tree growth model with actual tree growth. The first error can be expressed as the standard deviation of tree age at a certain tree height. The coefficient of multiple determination (R^2) expresses the second error or the fit of the model.

2.3.4.2 Tropical tree dendrochronology

In tropical forests the main problem is often to find tree species with annual growth signals that can be used for stem analyses.

Different techniques have been developed and tested. The most widely used include:

- **Ring counting in trees of known age -** the age of the tree is matched with the number of growth rings identified (WORBES, 1995).
- **Cross dating -** matching the ring width pattern within one stem and among different trees in a given stand (FRITTS, 1976). Based on skeleton plots (ring width expressed as bar chart) the sequence of differing narrow and wide growth rings is visualised. The sequences of different trees are then correlated. If ring width pattern among trees match each other, the possibility is high that rings mark actual annual growth. In cross-dating care must be taken to identify false and missing rings.
- **Cambium marking -** after cambium marking, wound reaction in the form of callus tissue becomes visible. If the date when the cambium was marked is known the growth rings established afterwards can be matched (SASS et al, 1995). Callus tissue formation can be due to natural (fire event, damage to trees) or artificial causes (marking in forest monitoring plots).
- **Radio-carbon dating -** ^{14}C techniques for age determination has been used in dendrochronology. Radioactive deposition can function as a tracer of age. Based on the

known half-life rates of radioactive elements, the age of individual tree rings can be determined (VETTER, 1995; WORBES, 1995).

- **Annual internodes** are visible at some tropical trees even after decades. They can be matched with tree ring structures (WORBES, 1995).

2.3.4.3 Datable tropical tree species

The first step in identifying trees species with annual growth signals is to screen the available literature. The available literature on Southeast Asia and British Colonial India was screened, as well as recent dendrochronology publications.

It is mentioned that some species of the *Meliaceae*, *Lauraceae* and *Leguminosae* families show annual growth rings (TROUP, 1921), but these did not occur in DDF in Thailand. Based on successful cross-dating of *Vitex cymosa* in Central Amazonia (WORBES, 1989) and *Pterocarpus angolensis* and *Vitex keniensis* in Africa (JACOBY, 1989; STAHLE et al., 1997) and because the frequency and dominance of species of these genera in DDF are known (FEHR, 1998), *Pterocarpus macrocarpus, Vitex peduncularis* and *Vitex limoniifolia* were selected for further evaluation.

2.3.4.4 Tree ring research in Thailand

In Thailand dendrochronology research has been restricted to few species (*Pinus kesiya*, *Pinus merkusii* and *Tectona grandis)*. The best dated species is *Pinus kesiya,* where chronologies lasting 350 years were established. Studies also showed that the two pine species show significant relations between tree growth, temperature and precipitation (BUCKLEY et al., 1995).

A dendroclimatological study conducted in northern Thailand established the chronology of 300 *Tectona grandis* trees from a total of 26 sites. The trees were between 79 and 312 years old (PUMIJUMNONG, 1995). Both studies relied on bore core samples.

However, WEYERHÄUSER (1998), studying bore core samples of 11 species occurring in deciduous forest and BUCKLEY et al. (1995), sampling 18 species from different forest types both failed to detect annual growth ring pattern on basis of bore core samples only.

Recently, results of cambium marking conducted 12 years ago by a Danish research project at Huai Kha Khaeng were investigated (BACKER, 1999). Out of 50 species, 15 could be matched with the number of tree rings established since. However, with the exception of *Afzelia xylocarpa* and *Vitex limoniifolia* none of the species occurs in deciduous forests.

2.3.4.5 Autecology of *Vitex limoniifolia*

Vitex limoniifolia belongs to the *Verbanaceae* family and like *Tectona grandis* and *Gmelina arborea* are used in forest plantations worldwide.

The species has a wide site distribution: in northern Thailand it can be found in evergreen and deciduous forest. This species occurs in elevations which can range from 200 m to 1,000 m a.s.l. (CMU HERBARIUM DATABASE, 2000). In western Thailand, in the Huai Kha Khaeng Wildlife Sanctuary, the species occurs in the same range of forest types, tree densities ranging from 10 to 30 trees ha^{-1} (FEHR, 1998; WEYERHÄUSER, 1998). The species usually occurs clustered.

Two more *Vitex* species (*V. peduncularis* and *V. canescens*) can be found under similar site conditions, the later more commonly in evergreen forest. The three species can be distinguished by their leaves (MAXWELL, 1999). *V. limoniifolia* has leaved stalks, *V. peduncularis* has hairy stalks and *V. canescens* has hairy leaves. First trials indicated that all species have distinct growth ring structures. This study focussed on *V. limoniifolia* as the most common one in deciduous forests.

Stem shapes of this species are frequently poor (SONO, 1974). Older trees are often wide-crowned, with many epicormic shoots. Whether this high proportion of "open-growth habit" individuals is natural (genetic) or the result of previous selective cutting is unclear.

The timber of *Vitex* is heavy, durable and was used for railway sleepers, chopping blocks and cutting boards. In Myanmar it is also used for making combs (TANANON, 1996). As the timber is termite resistant it is used for outdoor constructions.

Bending strength is 1,629 kg cm^{-2}, density 900 kg m^{-3} and average natural durability 11.7 years (TANANON, 1996). Compared to the *Dipterocarpaceae* species its timber is regarded as less valuable.

2.4 MATERIAL AND METHODS

2.4.1 The study area - an overview

The research was located in northern Thailand. The area is the most forested region in Thailand, DDF is one of the dominant forest types. North-south facing hills and ridges are the southern extensions of the Himalayan mountain range (CREDNER, 1935).

Northern Thailand also constitutes the catchment basins for the major rivers of the country. The mountain areas are home for many hill-tribe communities that rely on forest resources for their livelihood. This area is also of major importance for conservation due to a high biodiversity.

The Chiang Mai province was chosen as the improvement treatments were conducted under supervision at the silvicultural research centre and can be used later for teaching purposes by the nearby Chiang Mai University.

The town Chiang Mai is the regional centre, located in an alluvial plain (18°50’ N, 98°80’ E) and borders the foothills of the northern highlands. Due to fertile soils, this southerly aligned intra-mountain basin has a long history of settlements, mostly migrants from Laos and southern China (CREDNER, 1935). In the past, the mountainous surroundings served as a local source of timber. Over time selective timber utilisation and fires began to affect the forest vegetation. The arrival of the first Europeans in 1868 marked the beginning of forest exploitation. Because there is restricted space to expand agricultural production in the valley, there is a trend to convert the forests of the foothills to fruit tree plantations.

Due to the uneven distribution of the forest cover and the intermingled forest types, most distinguished vegetation forms did not correspond to a single forest type, as displayed in Fig. 2.1. However, the vegetation map provides a good overview about the remaining forests.

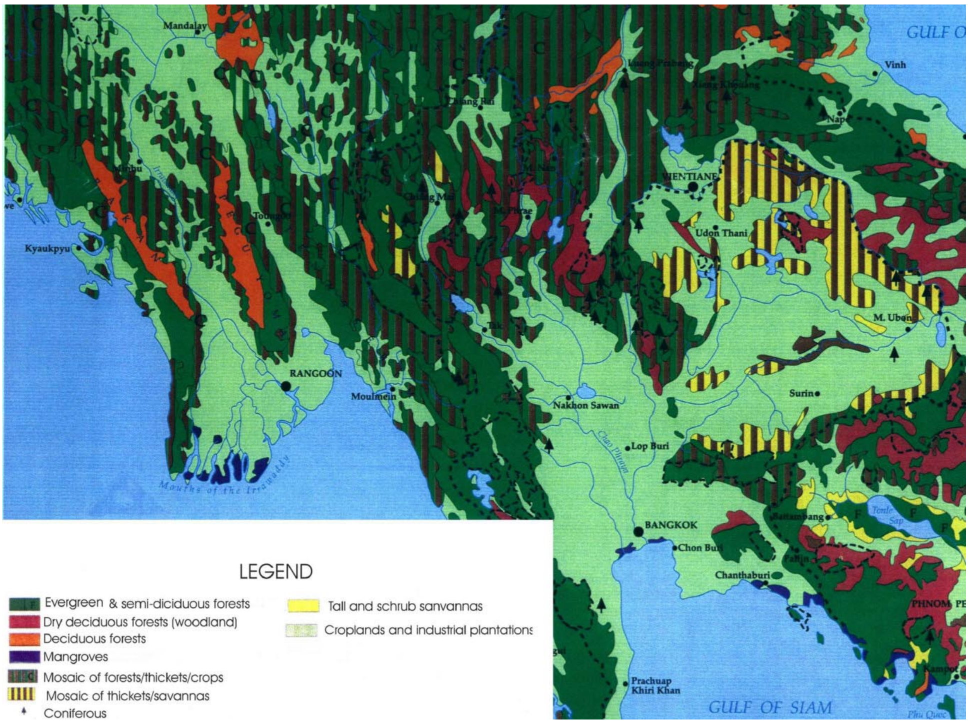

Fig. 2.1: Vegetation map of central and northern Thailand (BLASCO, 1995).

2.4.1.1 Main site, stand and silvicultural improvement treatment study sites

The study sites at Huai Som (HS) and Huai Rai (HR) are explained in this chapter. The location and the site conditions are noted. However, the forest stand will be described in detail in Chapter 3.

A preliminary survey of aerial photographs (black and white photographs 1:15,000), served to select sites and stands suitable for the study. Selection was based on the following criteria (in order of importance):

- Forest type classified according to the dominant canopy species;
- Representative for degraded DDF in northern Thailand;
- Proximity to local communities;
- Accessibility.

Aerial photograph interpretation and ground truthing were conducted together with staff of the regional offices of the Royal Forest Department. Based on this survey, two research locations were selected, where the forest type were representative for degraded DDF in northern Thailand: the HR village forest and a forest at the HS Silvicultural Research Station No. 1. Detailed information on the sites are presented in Tab. 2.1.

Tab. 2.1: Description of the HR and HS research sites.

Parameter		HR	HS
Location		Chiang Mai Province, Mae Taeng District, 30 km north-west of Chiang Mai (19°15'15 N; 98°45'49 E)	Chiang Mai Province, Mae Taeng District, 30 km north of Chiang Mai (19°15'10 N; 98°45'49 E)
Precipitation	mm y^{-1}	1,100	1,100
Mean annual temp.	°C	24 – 25	24 - 25
Elevation	m a.s.l.	485	380
Topography		Convex upper slope,	Straight upper and middle slope
Soil type (FAO)		Alisol	Arenosol
Ownership		State forest	State forest
Present use		Timber and NTFP utilisation	Silvicultural experiments

The **HR** site is located northeast of Chiang Mai. The forest near HR covers approximately 40 hectares. It is located north of the village, on the western slope of a south-north running mountain ridge. The location of the study area is displayed in Appendix 1. The forest has road access and is within walking distance of the village. Site conditions are more favourable, the trees height variability is increased the canopy is closed. Fruit tree plantations can be found on either side of the forest. The forest is intensively utilised for wood and NTFP. The forest canopy becomes increasingly open near the fruit tree plantations. In some parts bananas are planted within the forest and it is likely that the forest canopy will be fully removed in the future.

The **HS** study site (named after the stream) lies in the foothills about 30 km north of Chiang Mai, near the Mae Naa Bak village. The HS forest is approximately 200 hectares and belongs to a Silvicultural Research Station. In the northeast the forest borders the village. To the south and east runs the Chiang Mai – Phrae highway, separating the forest from the Mae Na Baa community reserve forest (see Appendix 1).

Both forests are classified as National Reserve Forests but locally they are considered to be community forests. Since 1993, the forest is under supervision of the Silvicultural Research Division of the Royal Forest Department. The forest is relatively young, but the forest canopy is closed. During the last 15 years, the cutting intensity was low.

2.4.1.2 Additional site productivity study sites

In contrast to the study sites at HR and HS, where stand investigations and silvicultural improvement treatments were conducted, the additional study sites at MN and PC serve for the site studies only.

Soil analysis data from comparable research sites at the Huai Kha Kaeng Wildlife Sanctuary, west Thailand were also used. These sites were described in TENNIGKEIT (1997), FEHR (1998) and WEYERHÄUSER (1998).

The site study areas at MN and PC were selected to cover a wider spectrum of site conditions. The Mae Naa Baa protection forest covers an area of 1,600 ha and is located close to the HS site. The experimental site lies at the foot of a slope, close to a small river that holds water well into the dry season which permits for an extended growing season. Parent material and soil types are comparable to the HS site. Due to its successful protection, trees are older and of bigger dimensions.

Another forest lies close to the Pa Cha Lua village in the Hot district, approximately 60 km south west of Chiang Mai. The geological parent material prevailing is limestone, the predominant soil type Cromi-Calceric Cambisol. Due to selective cutting and annual fires only older, malformed trees remain. In Appendix 3-5 a description of these study sites is provided.

2.4.1.3 Soil and geomorphological settings

In northern Thailand Palaeozoic, partly Praecambrium parent material dominates, characterised by Palaeozoic schist and Precambrium gneiss as well as phyllites, limestone and sandstone. On top of this is a layer of Permotriassic and Jurassic sediments composed of sandstone, silt and limestone (KUBINIOK, 1992).

Though worldwide only five percent of tropical soils are derived from limestone (SCHULTE & RUHIYAT, 1998), in Thailand these limestone formations are widespread (ASHTON, 1990). They can be found mainly on steep ridges (CREDNER, 1935). However, their value for agriculture is relatively low due to their poor water retention capacity. Usually these soils are deficient in iron and zinc, some also show imbalances of calcium, magnesium and potassium (SCHULTE & RUHIYAT, 1998).

At the four experimental research sites, parent material of three different geological ages occur (see Appendix 5). At MN, HR and the upper slope of HS1, mainly wind-borne quartz-rich material was sedimented during the ice ages. The HS2 (middle slope) profile shows the diluted Palaeozoic sandstone basement underneath. The Limestone at the PC site was established in the lower Ordovicium (KIRSCH, 1996).

From the parent materials (see Appendix 5) three different soil types developed.

The soil types at MN and HS are luvic (parent material less than 30 cm deep) developed Arenosols. They are sandy and are characterised by poor water and nutrient retention capacity.

The high proportion of sand and the low eutrophic level are the main differentiation criteria to the haplic Alisol at HR.

Cromi-calceric Cambisol (called Terra fusca in older classifications) was found at **PC**. This soil type has clear distinguishable properties (high pH, clay and calcium content) compared to the other sites.

2.4.1.4 Climatical settings

The precipitation data of the Mae Joe University meteorological station, located close to Chiang Mai, provided information on annual and monthly rainfall dating back 30 years.

The annual precipitation variability between different years is high (see Fig. 2.1). The variance between the upper and lower extremes is higher than the mean annual rainfall. Significantly wet years occurred in 1970 and 1975. Extremely dry years occurred in 1982, 1993, 1997 and 1998.

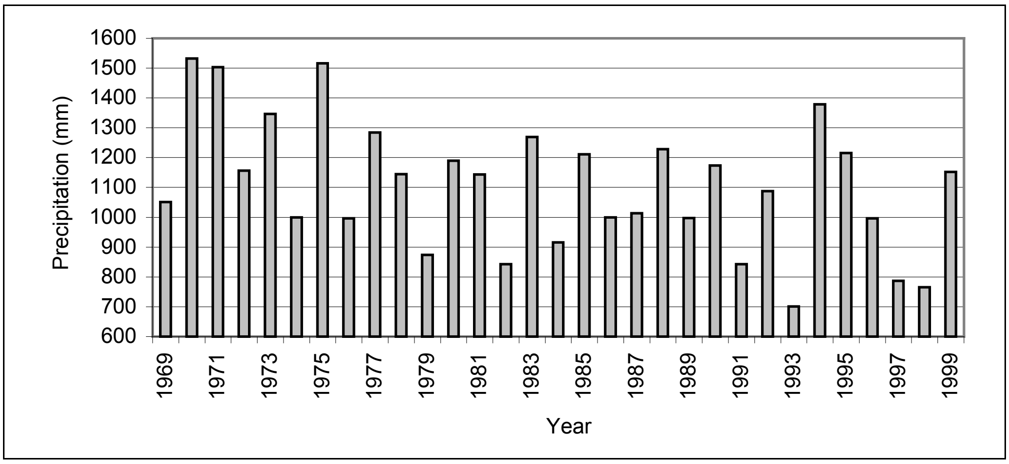

Fig. 2.1: Annual precipitation between 1969 to 1999 at Mae Joe University.

The bimodal annual precipitation pattern is characterised by a dry season from November to April and a rain season between May and October (see Fig. 2.2). However, during the dry season, on average, it rains at least one day per month. In June there is a slight rainfall depression before the main rain season starts in July. Mean annual rainfall during the observation period was 1,100 mm at Mae Joe.

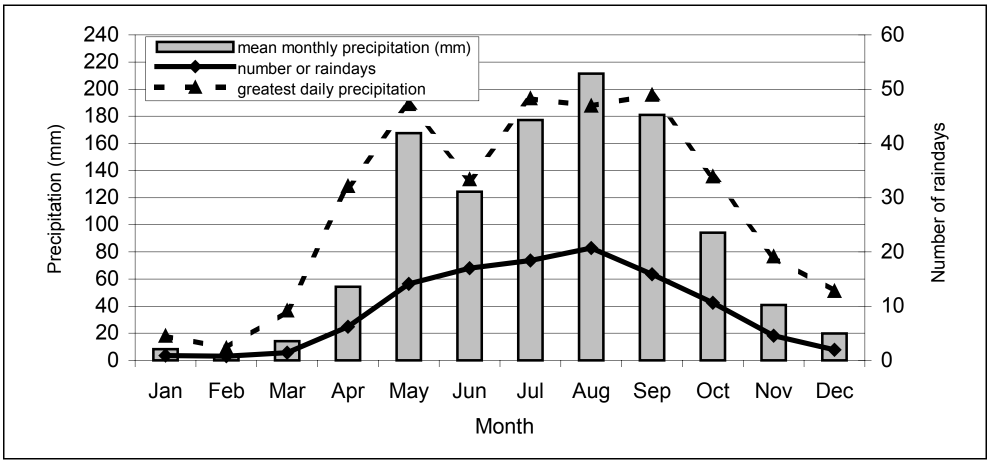

Fig. 2.2: No. of rainy days, mean monthly and greatest daily precipitation at the Mae Joe University.

Average values between 1969-1999.

Mean temperatures at Chiang Mai City are 20-24°C in the cool season from November to February. The mean temperature of the coldest month (January/February) lies rarely below 20°C, minimum temperatures rarely falls below 8°C (BLASCO, 1983). In April, the monthly temperatures rise sharply to a peak of 29°C. Between May and October mean monthly temperatures are between 25 and 28°C (ELLIOTT et al., 1994).

2.4.2 Soil analyses

2.4.2.1 Field data collection

At each study site a one metre deep soil pit was dug to analyse and compare soil parameters.

Placement was 5 m apart, north of one of the randomly selected *Vitex limoniifolia* individuals used for dendrochronology studies. At the HS site one additional soil pit was established, following the same site selection design. The aim was to get information on intra site variability.

From each soil pit samples were extracted from the following soil depths: 0-5 cm; 5-20 cm; 20-40 cm and 40-60 cm.

The soil type determination followed the FAO-UNESCO (1994) classification. Profile description, was conducted according to the AG BODEN (1994) inventory procedure.

In each distinguished soil layer fine root penetration depth and intensity was determined to consider ecological soil properties. The fine root abundance per 10 cm^2 was recorded and classified according to OOMS (1992). The following classes were distinguished 1-5 roots/10 cm^2; 5-20/10 cm^2; 20-50/10 cm^2 and ≥50/10 cm^2.

2.4.2.2 Laboratory analyses

Physical and chemical soil parameters were also analysed in accordance to OOMS (1992). The pH was determined in H_2O (1:1). Organic matter was studied by measuring the carbon content using the Walkley & Black method. Nitrogen was analysed with the Macro-Kjedahl digestion distillation unit. Cation exchange capacity was measured after titration to pH 7. For the evaluation of available phosphorus, the Bray II method was used.

2.4.2.3 Soil data analysis

The results from the northern research sites and from Huai Kha Khaeng, Wildlife Sanctuary, west Thailand were combined. For further analysis, data from the four studied horizons were condensed by taking the mean. Cross-correlation analysis was applied to compare soil parameters.

Principal Component Analysis

In order to reduce the number of parameters and to detect structure in the relationship between soil parameters, Principle Component Analysis (PCA) was applied (GUPTA, 1996). The method reduces large numbers of correlated variables into smaller numbers of independent variables the so-called principal components (ORLOCI, 1978).

The basic principle of PCA is to express the variables by principal components in such a way that it explains as much variance as possible. The first principal component expresses most variance, consecutive components increasingly less (STATISTICA, 1995). The variance extracted by the components is called eigenvalue. A screen test, a graphical method to plot the cumulative eigenvalues, was applied consecutively to decide whether more factors should be integrated. The standard varimax rotation method was used as the principal component rotation strategy. This rotation method aims at maximising the variance of the squared raw principle component loadings across variables for each principle component (for details see STATISTICA, 1995; BACKHAUS, 1996).

An additional task is to estimate the communality for each variable, that is the proportion of the variable variance explained by all components (BACKHAUS, 1996). The unique variance of each variable is then the respective variable's total variance minus the communality.

After determining principal components, they were correlated to the variables included in the analysis, the so-called factor loading. It describes the relations between the components and the variables. A t-test with a p-level less 0.05 was applied to identify significant correlation. To reduce undesired weighting of parameters, data had to be standardised (see BACKHAUS, 1996).

Cluster Analysis

While PCA serves as an exploratory instrument, Cluster Analysis is needed to classify research sites based on parameters most closely correlated with principal components.

Cluster Analysis encompasses a number of possible classification algorithms (GAUCH, 1982; KENT & COCKER, 1995). In this study an agglomerative method was used to join the study sites according to their similarity in an increasing hierarchy. Similarity was expressed with the help of Euclidean distances, a geometric distance measurement in multidimensional space (JONGMAN et al., 1987). Linkage between the different sites was completed using Ward's method. It is also called minimum variance clustering because at each calculation step, an attempt is made to minimise the sum of squares of any two (hypothetical) clusters that can be formed. This method is very efficient to differentiate groups and is stable in relation to parameter transformations (BACKHAUS, 1996).

In this case, principle components were extracted to minimise redundancies due to correlated parameters. Cluster Analysis was then applied with the two parameters most significantly correlated to the principle components.

2.4.3 Vegetation analyses

2.4.3.1 Field data collection

An inventory of the undergrowth vegetation was conducted in January 1999, therefore only the dry season vegetation is represented. At each research site, vegetation below 1.3 m was sampled. Three research plots with a radius of 5 m (total plot size of 78.5 m^2) were placed 10 m apart (four plots at the PC site), consistently north of each *Vitex limoniifolia* individual sampled for site index studies. Species dominance and abundance was recorded following the method developed by MUELLER-DOMBOIS (1974). See also Tab. 2.1.

Tab. 2.1: Species cover abundance scale (MUELLER-DOMBOIS, 1974).

Symbol	5	4	3a	3b	2a	2b	1	s	r
Plant cover %	≥75	75-50	50-33	33-25	25-10	10-5	< 1 very scattered	< 1 seldom	< 1 rare

Species were identified on site. Those that could not be clearly identified were taken to the Chiang Mai University to compare with the herbariums reference collection.

This sampling procedure was used to compare the vegetation composition with the information from the CMU HERBARIUM DATABASE (2000).

2.4.3.2 Data analysis

The intra and inter site species variability of tree and non tree species occurrence was investigated with the Sörenson-Index. The index is calculated using the following equation (JONGMAN et al., 1987):

$$CC = \frac{2c}{a+b} \text{ where}$$

CC = Sörenson index
a and b = Number of species unique to each site
c = Number of species shared by the two sites

The site information on species of the CMU HERBARIUM DATABASE (2000) was used for quantitative site habitat analysis.

- Initially, the habitat information of the identified species was taken from the database. The database is a comprehensive source and contains information from seven sites covering more than 3,000 species.
- Secondly, the forest type nomenclature from the CMU HERBARIUM DATABASE (2000) system was simplified, as the aim of the research approach was to focus on species that indicate DDF conditions. Therefore species that did not occur in DDF (**NODDF**), occur exclusively in **DDF** or species with unknown habitat or prevail in DDF as well as other forest types with no indicator value (**NOI**) were classified (see Tab. 2.1).
- Thirdly, the species occurring on the investigated research sites were classified to the distinguished forest types. Based on this, it was possible to provide a quantitative description of the site flora.

Tab. 2.1: Forest type classification used for site habitat delineation.

Classified forest type	Definition
NODDF	Species that occur in several forest types but not in DDF
DDF	Species that occur exclusively in DDF
NOI	Species that occur in DDF and other forest types or species with unknown habitat

2.4.4 Tree ring investigations

2.4.4.1 Field data collection

In an exploratory phase, stem sections of *Pterocarpus macrocarpus* and *Vitex limoniifolia* were taken to test whether annual growth rings could be identified. *Pterocarpus macrocarpus* was later eliminated from the analysis as it was not possible to cross-date the age in the different intersections.

The amount of extractable trees per research site was limited to three trees. Only at HR were four trees selected. Tree selection was performed in two steps:

- Firstly, stem quality and DBH was recorded for all *V. limoniifolia* trees of social position 3-5 (compare Tab. 2.1) in the area. Furthermore stems had to be straight and free of major branches at the lower part and healthy as well as undamaged.
- Secondly, a tree map was drawn for those *V. limoniifolia* trees which fulfilled the social position and quality requirements. Based on this map the trees closest to each other were selected as research material, to minimise the site variability as far as possible.

The investigated trees differed from each other in respect to age and dimension, because the stands at HR and HS were much younger and more homogenous than those at MN and PC. However, the sampled *V. limoniifolia* trees all belonged to the upper forest canopy and were between 20 and 70 years old. The tree material is described in Tab. 2.1.

The selected trees at PC site were the oldest trees sampled and have an extremely low height diameter ratio. It can be assumed that they grew up with less competition than the other investigated trees. The highest height diameter ratio was recorded for tree no. 3 at HR.

Tab. 2.1: Numerical description of the sampled *V. limoniifolia* trees.

Research site	**Tree No.**	**Age***	**Social position****	**DBH**	**Crown projection area**	**Live crown length**	**Total tree height**	**H/ DBH**
		years		cm	m²	m	m	
Huai Rai Site code: HR	1	20	3	9.5	5.4	5.5	6.9	0.73
	2	24	3	8.1	5.8	3	5.6	0.69
	3	22	4	7.2	2.4	4.1	7.9	1.10
	4	31	5	15.6	10.7	6.4	9.8	0.63
Huai Som Site code: HS	1	27	3	7.3	2.1	3.5	6.8	0.93
	2	31	3	11.9	7.1	3.3	8.8	0.74
	3	26	4	11.1	3.9	5.8	9.6	0.86
Mae Naa Baa Site code: MN	1	48	4	21.3	13.1	8.5	17.4	0.82
	2	37	3	12.3	5.1	12.8	11.8	0.96
	3	56	3	23.3	30.8	10.1	20.4	0.88
Pa Cha Lua Site code: PC	1	61	3	18.3	48.4	7	11.6	0.63
	2	63	4	24.0	37.7	10.6	13.8	0.58
	3	68	3	26.5	48.8	12.7	16.3	0.62

* Tree age based on age estimation of the first stem section (see Chapter 2.4.4.5); ** For social class classification see Dawkin's classification in Tab. 3.1.

2.4.4.2 Tree anatomic structures

V. limoniifolia has a semi-ring porous wood structure. A prepared and polished stem section is displayed in Fig. 2.1. Annual ring boundaries can be detected quite clearly. However, ring widths are not very uniform.

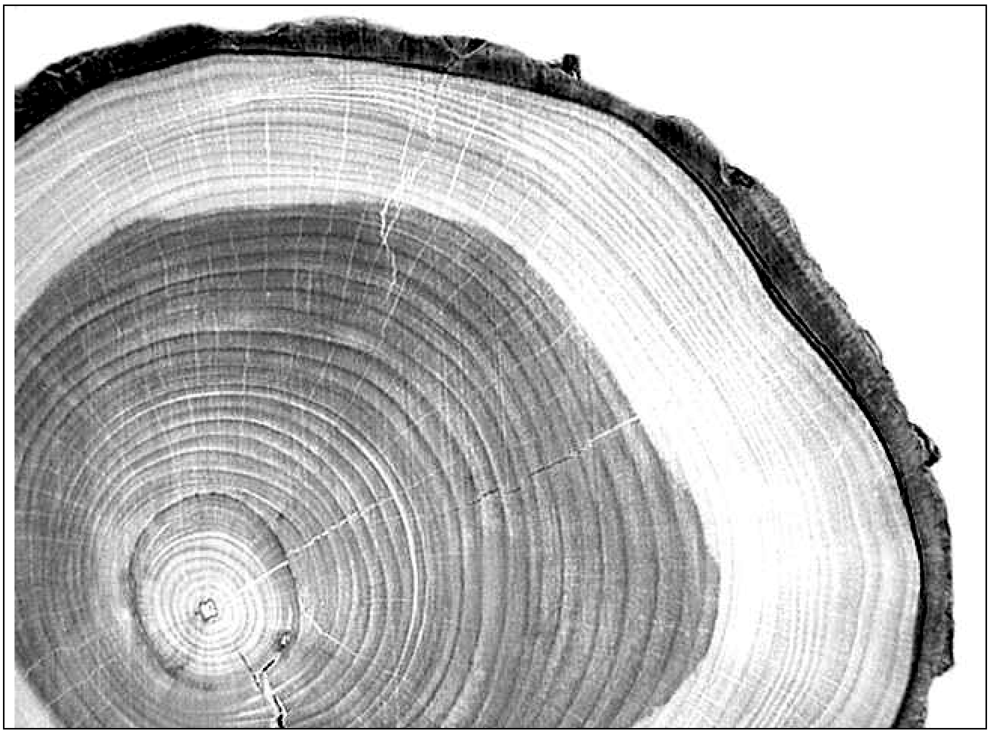

Fig. 2.1: Stem section at 1.0 m of the 68 years old *V. limoniifolia* tree no. 3 at the PC site.

2.4.4.3 Stem section extraction and analysis

After felling the trees, stem discs measuring 4 cm thick were extracted at 0.1 m, 1.0 m, 1.3 m, 2.0 m and then in one metre intervals to the top of the tree. Each segment received a marker to indicate north and was then air dried. At the laboratory of the Institute of Forest Growth at Freiburg University, all stem sections were sanded with an industrial band sander. For height growth analyses the number of tree rings was recorded at all stem sections along the cardinal compass bearings.

2.4.4.4 Estimation of true tree heights

To estimate true heights from stem sections, one has to consider that the determined height at a certain age (that is the amount of growth rings at stem section) will almost always occur at some intermediate point along the leader (CARMEAN, 1972). If trees are not sectioned at the terminal bud scar, interpolating models have to be applied. Different models to assign the height to a certain age have been reviewed (DYER & BAILY, 1987). Based on this, the method from CARMEAN (1972) was applied, with an adjustment from NEWBERRY (1991). Carmean's method implies that on average in the middle of a year's height growth the rate is constant.

The mathematical expression for this assumption was applied in the notation from DYER & Baily (1987):

$$H_{ij} = h_i + [(h_{i+1} - h_i) / (r_i - r_{i+1})] / 2 + (j - 1) [(h_{i+1} - h_i) / (r_i - r_{i+1})]$$

where,

H_{ij} = Estimated total height for growth ring j based on section point i
h_i = Height at the i^{th} section point
r_i = Number of growth rings at the i^{th} section point
j = Growth ring number (assuming the pith as the starting point), $j = 1, ... r_i$

The adjustment from NEWBERRY (1991) is necessary to consider the top of the tree. Above the last intersection (h_{i+1}) the approach is not able to estimate last year's height growth and the average annual height growth will be underestimated. Subtracting 0.5 years from the interval ($r_i - r_{i+1}$) solves this problem. Accordingly, for the top section the equation is modified to:

$$H_{ij} = h_i + [(h_{i+1} - h_i) / (r_i - r_{i+1} - 0.5)] / 2 + (j - 1) [(h_{i+1} - h_i) / (r_i - r_{i+1} - 0.5)]$$

2.4.4.5 Age estimation for the first stem section

For stem analyses the age at the first stem section has to be estimated or a reference age based on the age at the first stem section has to be used. Some authors recommend using the reference age starting at the first stem section (CURTIS, 1964; MONSERUD, 1984; BIGING, 1985) They argue that early growth is only poorly related to site quality and a source of undesirable variation. Realising the same problem, CARMEAN (1972) and UNTHEIM (1996) estimate the age at the first stem section to avoid the term reference age at a certain tree height. This term is difficult to interpret when the height of the first extracted stem section varies. It implies that reference age is no longer comparable.

For the studied species no guidance exists on how to estimate the age at the first stem section. For practical reasons the assumption was made that trees at 0.1 m height were 1 year old and trees at 1.3 m 5 years old. This assumption is based on the observed median annual height increment of *V. limoniifolia* seedlings in 1998 and 1999 (25 cm y^{-1}) at HR.

2.4.4.6 Tree growth model

Growth models have to accomplish many needs. They are supposed to be as simple as possible. Their curves should make sense biologically and they should be capable of describing the relationship between tree height and tree age for any given species. Furthermore, they must be flexible to fit different data sets. A comparative study of different growth functions showed that most functions rely on erratic predictions at certain points in time (CARMEAN, 1972). A relatively poor fit at the reference age must be avoided. Judging by the high regression coefficients for individual equations, non-linear sigmoid curves are most appropriate. They are also relatively stable for estimations beyond the collective data.

A widely used and tested growth function in temperate forest ecosystems is the model from Chapman Richard (RICHARD, 1959; CARMEAN, 1972), this was applied for the study:

$H = b1*(1-e^{-b2age})^{b3}$

where,

H = Tree height at any age
b1 = Coefficient expressing asymptotic tree height
b2 = Coefficient determining rate of tree height growth
b3 = Coefficient determining initial pattern of height growth
e = Base of natural logarithm

In tropical forest plantations this model has already been applied (AMBROSE, 1994; URIATE, 1997). The function fitted all height-age data best. A weighted least square technique was employed to maximise the regression coefficient.

2.4.4.7 Site index curve fitting

Each individual experimental tree attains a specific growth function. Commonly, a non linear regression model can be fitted to the pooled tree observations to come up with a site index curve. There are also other approaches (BIGING, 1985), but due to the small sample size, pooled data was used to fit site index curves.

The site index was compared at a reference age of 30 years so as to avoid extrapolation of site index curves beyond measured values. In Thailand this age is used for site index comparison in teak plantations (SAHUNALU et al., 1992).

2.5 RESULTS

2.5.1 Soil aspects

2.5.1.1 Ecological soil properties

The ecological soil properties were similar at all research sites, illustrated by their root penetration intensity and depth. Even in the compacted soils at HR and HS, the well-adapted tree species can expand their roots down to 80 cm soil depth.

The highest root intensity at all sites was observed in the top soil layer (between 20-50 fine roots per 10 cm^2), With increasing soil depth root intensity decreased, between 40-60 cm soil depth less than 5 fine roots occurred per 10 cm^2.

2.5.1.2 Physical and chemical soil properties

At the research sites four or five different soil horizons were differentiated. The topsoil horizon was between 6 and 10 cm deep. Except on limestone (PC) this horizon was followed by a leached B horizon. The parent material starts at 40 to 50 cm depth (see Appendix 5).

Soil textures at the research sites range from loamy sand to clayey loam (US soil taxonomy system). At HR and HS, on a middle slope setting, sandy loam is the dominant texture. On the upper profile at HS and the MN profile, sandy loam can be found only below 40 cm. The horizons above contain larger sand and lower silt proportions and were classified as loamy sand. At the PC profile the clayey loam is characterised by lower sand and larger silt proportions.

The **coarse fractions,** important for water and nutrient retention, are presented along the profile in Fig. 2.1. At each site, sand content decreases from the top soil to the lowest soil layer, while clay increases. However, at HR, HS and MN, in the first 40 cm, clay content is less than 15 %. A clear, soil-depth-dependent silt fraction pattern is not visible. Silt content at HS2 is remarkably high.

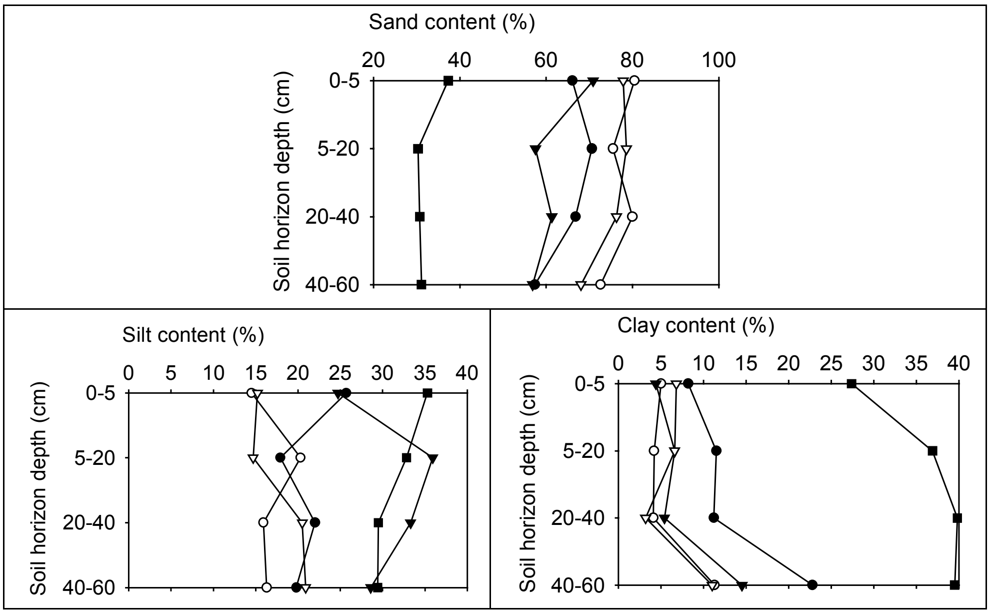

Fig. 2.1: Soil Texture (sand, silt and clay) of the 5 different research sites. Note the different scales!

Site codes: —●— HR —○— HS 1 —▼— HS 2 —▽— MN —■— PC

Clear differentiation patterns in soil texture and chemical properties were visible in soils occurring on calcareous parent material as at PC and on sandy parent material as on all other sites.

Soil chemical properties are displayed in Fig. 2.2. Almost all investigated parameters were decreasing from the top layer to the lowest layer.

When the soil profiles were analysed (in January, the middle of the dry season) no organic horizon was visible.

The phosphorus content was much higher at the MN site than at all the other research sites. In many respects chemical properties were more favourable at MN and HR than at the two HS sites.

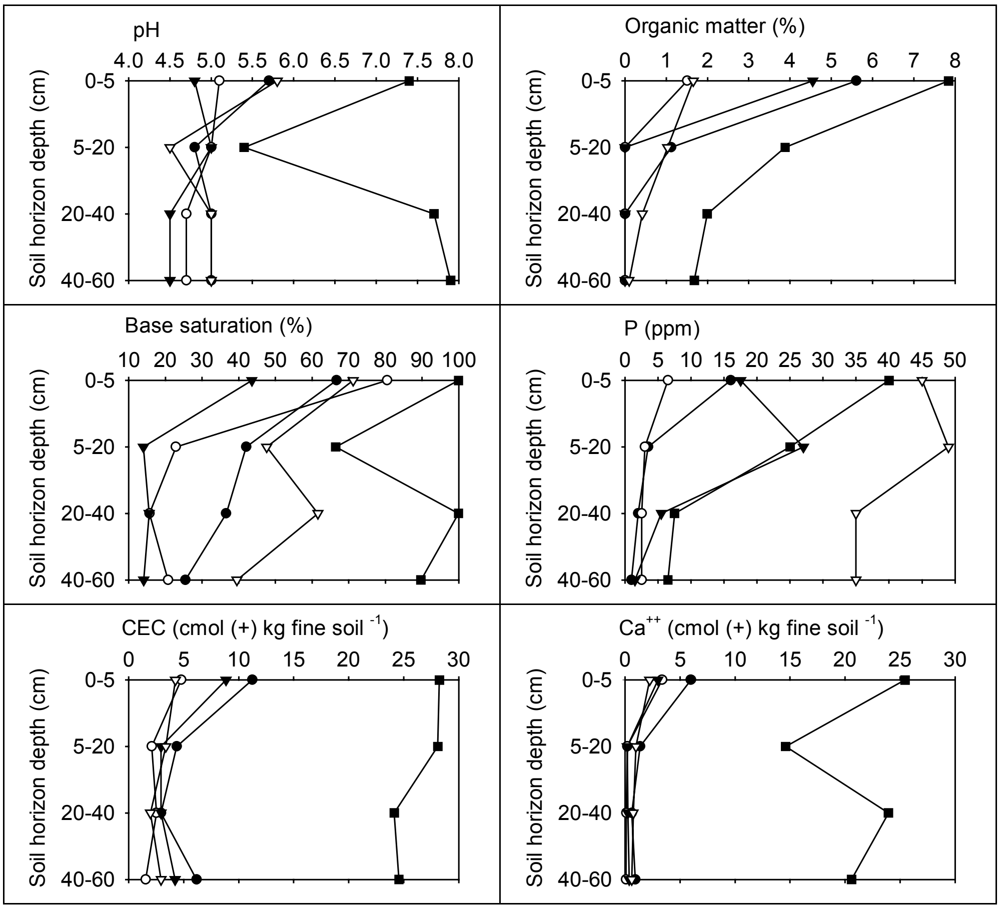

Fig. 2.2: Chemical soil properties in different soil depth. Note the different scales!

Side codes: —●— HR —○— HS 1 —▼— HS 2 —▽— MN —■— PC

2.5.1.3 Correlation between soil parameters and study sites

The chemical and texture properties from the investigated soils were highly correlated (see Tab. 2.1).

Tab. 2.1: Cross correlation between the investigated soil parameters.

	pH	OM	P	Ca	Mg	K	BS	Sand	Silt	Clay
pH										
OM	0.48									
P	-0.22	0.40								
Ca	**0.66***	**0.82***	0.38							
Mg	0.04	**0.74***	**0.78***	**0.73***						
K	**0.92***	0.58	-0.34	**0.60***	0.04					
BS	0.32	0.51	0.59	**0.77***	**0.78***	0.17				
Sand	**-0.74***	**-0.87***	-0.13	**-0.81***	-0.46	**-0.84***	-0.38			
Silt	0.56	0.54	-0.16	0.46	0.06	**0.72***	-0.04	**-0.82***		
Clay	**0.72***	**0.93***	0.28	**0.88***	**0.62***	**0.77***	0.57	**-0.94***	0.57	

Significant results with a p-level < 0.05 are highlighted with an asterisk.

For soil texture this was anticipated, but silt and clay were not significantly correlated. Sand was the only parameter significant negatively correlated to any other parameter.

Some chemical soil parameters were also significantly correlated with each other, for example magnesium with phosphorus, calcium and organic matter. Base saturation was significantly correlated with calcium and magnesium. The relation between pH and potassium, organic matter and clay content shows correlation coefficients ≥ 0.9.

Based on a Principle Component Analysis (PCA), 86 % of the total variance between sites can be explained by two principal components, thus it was considered not necessary to retain more principal components. The first principal component explains 57 % of the variance, the second explains 29 % (see Tab. 2.2).

Soil parameter	First principal component	Second principal component
pH	0.71*	-0.57
OM	**0.91***	0.08
P	0.36	**0.84***
Ca	**0.96***	0.10
Mg	0.70*	0.67
K	0.72*	-0.68
BS	0.69	0.52
Silt	0.57	-0.57
Clay	**0.97***	-0.09
Explained variance	**5.13**	**2.57**
in % of total variance	**0.57**	**0.29**

Tab. 2.2: Factor loading between the first and second principal components and the investigated soil variables.

Significant components are marked with asterisks.

Organic matter, calcium and clay content had the highest factor loading with the first component. Phosphorus displays the opposite factor loading. The other two groups were scattered within these extremes. Magnesium and base saturation and silt, pH and potassium belong to these groups.

To visualise the distance of the parameters along the two principal components, results of the PCA are presented in a scatter plot in Fig. 2.1: This illustrates the grouping of soil parameters which were significantly correlated, independently from the cross correlation (compare Tab. 2.1).

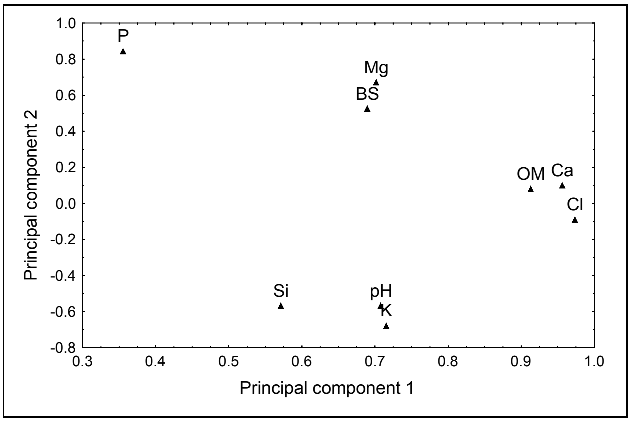

Fig. 2.1: Position of soil parameter as derived from Principal Component Analysis.

The input data for the PCA are summarised in Tab. 2.2. The sand parameter was not considered during PCA computation, as its variability is included in the two other texture fractions.

Finally, a **Cluster Analysis** was conducted to investigate the similarities between the study sites, based on phosphorus and clay content.

The resulting vertical tree diagram shows that the greatest similarity exists between the two HS sites (see Fig. 2.8). The MN site shows more similarity to the HS and HR sites than the PC site.

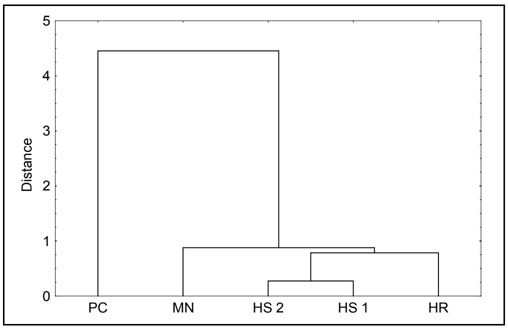

Fig. 2.2: Position of study sites as derived from Cluster Analysis.

Similarity and linkage based on clay and phosphorus content.

2.5.2 Vegetation aspects

2.5.2.1 Diversity of undergrowth species

Of the 155 tree and non tree species on the overall sampling area of 1020.5 m^2, about a third were tree species, another third were herb species and the remainder belong to the other forms (see Tab. 2.1).

Habit	Number of species	
	1020.5 m^2	%
Tree	47	31
Treelet	22	14
Woody climber	7	5
Vine	13	8
Shrub	10	6
Herb	45	29
Unknown habit	11	7
Species total	**155**	**100**

Tab. 2.1: Number of species at all sites with a certain habit.

Species and their importance values are listed in Appendix 6-7.

The intra site variability of tree and non tree species richness was relatively low at the HR, HS and MN sites compared to the PC site (see Tab. 2.2).

Tab. 2.2: Tree and non tree species richness and variability at all research sites.

Research site	Number of sample plots	Total species richness		Mean species richness per research plot		Standard deviation	
	(plot size 78.5 m^2)	tree	non tree	tree	non tree	tree	non tree
HR	3	15	33	6	18	1	1.2
HS	3	12	38	10	21	1.5	3.0
MN	3	27	52	17	29	1.7	1.7
PC	4	24	47	9	20	5.8	13.8

The results of the PC site were strongly influenced by one extraordinary sampling plot. There, as many as 40 non tree species were identified. Thus, at this site an additional sample plot was investigated, but even then the standard deviation was high.

On the MN site by far the highest mean species richness per plot was recorded (on average 17 tree and 29 non tree species per plot). Mean species richness at the other three research sites were approximately equal.

2.5.2.2 Species similarity within and between sites

Predictably, species similarities were higher within a given site than between two sites. Values within one site ranged from 0.4 to 0.6, which translates into 40 up to 60 % overlap between species at one site. Between sites values ranged from 0.3 to 0.4. The highest species similarity between two sites was discovered between HR and HS.

2.5.2.3 Species habitat as an indicator of site conditions

Fig. 2.1 shows the habitat classification of each site with the breakdown between tree and non tree species. The HR and HS sites displayed the most DDF **trees species** (HR 5 tree sp.; HS 6 tree sp.; MN 1 tree sp.; PC 3 tree sp.). In contrast the MN and PC sites had more tree species relating to other forest types (HR 1 tree sp.; HS 0 tree sp.; MN 7 tree sp.; PC 5 tree sp.).

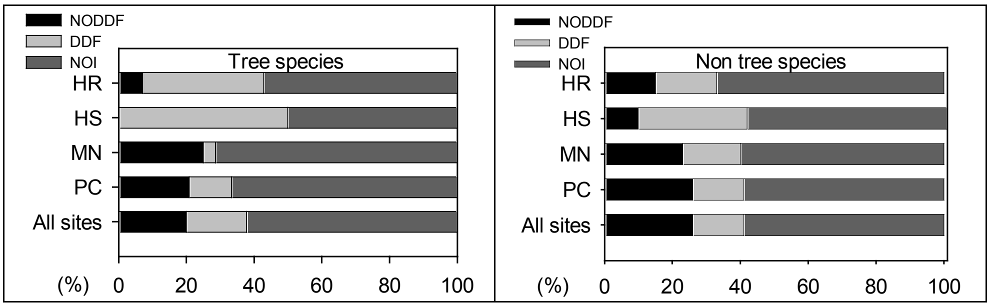

Fig. 2.1: Tree and non tree species habitat classification.

Species codes: **NODDF** (species that occur in several forest types but not in DDF); **DDF** (species that occur exclusively in DDF); **NOI** (Species that occur in DDF and other forest types or species with unknown habitat)

Tree species composition between HS and HR indicated similar habitat conditions, while differences between the tree species composition at MN and PC were visible. At the MN site the only tree species that would indicate DDF site conditions was *Shorea siamensis*.

Habitat information on **non tree species** showed similar results. Species composition at HR and HS sites indicate DDF site conditions, while at MN and PC the non tree species indicate the prevalence of MDF and evergreen forest types.

At all sites more than 50 % of the recorded species did not provide any site quality information, either because habitat information was unknown or they occur frequently in DDF as well as in other forest types. The species that were used to indicate DDF site conditions are displayed in Tab. 2.1.

Tree species	Non tree species
Dipterocarpus obtusifolius *Dipterocarpus tuberculatus* *Morinda tomentosa* *Ochna integerrima* *Quercus kerrii* *Shorea siamensis* *Symplocos racemosa* *Tristaniopsis burmanica*	*Abrus precatorius* *Borreria brachystema* *Dunbaria bella* *Ellipelopsis cherrevensis* *Eulalia leschenaultiana* *Gardenia obtusifolia* *Grona grahamii* *Gymnema griffithii* *Heteropogon triticeus* *Inula indica* *Knoxia brachycarpa* *Memecylon scutellatum* *Mnesithea granularis* *Polytoca digitata* *Premna herbacea* *Schizachyrium sanguineum*

Tab. 2.1: Typical DDF tree and non tree species (CMU HERBARIUM, 2000).

From the habitat analysis it can be concluded that both tree and non tree species can be used to distinguish site conditions at the research sites. However, it was more difficult to use the distribution of non tree species to distinguish between study sites, as many DDF related non tree species occurred on all sites.

2.5.3 Site index curves for Vitex limoniifolia

Site index curves were based on pooled site tree data. The parameterisation of site-index growth models, the regression coefficients of the fitted site index curves are shown in Tab. 2.1.

Site	HR	HS	MN	PC
Asymptotic height (b1)			19.5933	
Height growth rate (b2)	0.0016	0.0015	0.0575	0.0010
Initial height growth pattern (b3)	0.9504	1.0224	1.6439	0.9962
R^2 of the pooled site curves	0.94	0.80	0.91	0.95

Tab. 2.1: Site index parameterisation.

Asymptotic tree height could only be calculated for the MN site, because mean height growth of the trees at HR, HS and PC had not yet cumulated.

In Fig. 2.1, site index curves for the four sites investigated are plotted. It implied that DDF occurred on different site conditions based on the sampled trees.

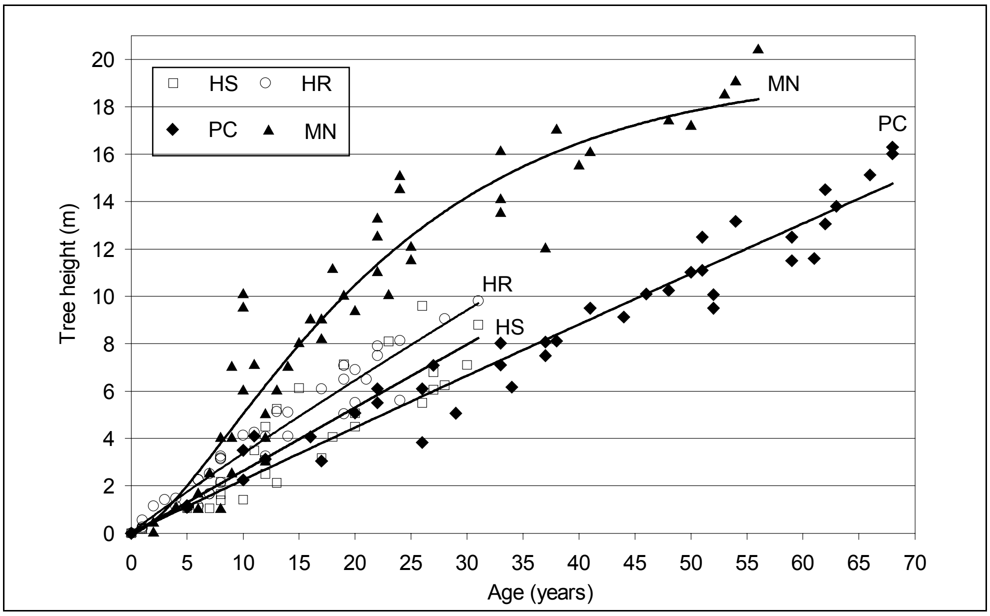

Fig. 2.1: Fitted site index curves for *Vitex limoniifolia*.

Finally, site indices calculated at a reference age of 30 years are displayed in Tab. 2.2. Site index at MN was 14.2 m. It was approximately twice as high as the site index at PC. Site indices were decreasing from MN, HR, HS to PC.

Site	Site index	Individual site tree height	
		max.	min.
	m	m	m
HR	9.6	11.3	6.8
HS	8.1	9.7	7.1
MN	14.2	15.7	11.8
PC	6.9	7.1	5.6

Tab. 2.2: Site index table at reference age 30 years.

2.6 DISCUSSION

2.6.1 Material and methodological aspects

Soil sampling was generally restricted to one sample on most sites. Intra site soil variability was studied at the HS site where two soil samples were taken. The Cluster Analysis showed that soil similarity within one site, investigated at HS, was greater than between any other two sites investigated. This indicated that any one site is well represented by one sample.

In tropical India, studies on a homogenous 2 hectare plot in a tropical moist forest found only minor variability in soil texture and pH content within the 100 investigated samples (SUJATHA & THOMAS, 1997).

The methods used to investigate **soil differences** proved sufficient to differentiate site conditions. It is still unclear whether the investigated soil parameters can be used to determine site productivity levels. The water holding capacity and soil moisture content are important parameters triggering growth in dry deciduous forests (WHITMORE, 1988; REICH & BORCHERT, 1984). Due to limited resources, it was not possible to investigate these parameters throughout the seasonal fluctuations. To what extent they can be assessed indirectly with the investigated parameters has not been determined. It is certain, that the determination of site productivity would greatly benefit from additional information on these factors. There is strong demand for models predicting these parameters.

Results from soil surveys in west Thailand were compared with the results from northern Thailand. Significant intercorrelation existed between soil parameters. **PCA** proved to be a powerful tool in this case, explaining most of the soil variance and detecting correlated parameters.

Revised applications of PCA are recommended. Research using multiple regressions to investigate tree species composition and growth in relation to different soil parameters were conducted in Thailand (KUTINTARA, 1975; BUNYAVEJCHEWIN, 1983b, 1985) and in Costa Rica (HERRERA et al., 1999). In these studies up to eleven different soil parameters were used as independent variables. However, without further explanation on how to deal with collinearity problems among parameters these models are difficult to interpret.

PCA as applied in this study proved to be suitable to find independent parameters explaining the variability, while at the same time minimising collinearity problems.

Vegetation of dry season flora was analysed. The number of tree species on the HR and HS site was 15 and 12 tree species per 236 m^2, respectively (see Chapter 2.5.2.3). During the stand studies (see Chapter 3), 30 and 27 seedling species were recorded on 480 and 600 m^2 at HR and HS respectively. This indicates that with increasing sample size species richness also continues to increase.

The proportion of non tree species covered during vegetation analysis might be lower still. However, vegetation sampling was not primarily aimed at assessing species richness, the main goal was to evaluate if sites can be distinguished based on their flora. For this purpose the sampling intensity used was sufficient.

Vegetation analysis yielded information on the presence and absence of species. This technique does not account for species abundance and dominance. Using this information during site habitat analysis, might have increased the value of site delineation. Species abundance and dominance information was recorded during sampling, but due to the small sampling size it provided no additional value for the site delineation approach. Nevertheless this information will be utilised for further studies at Chiang Mai University.

The selection of research sites and sampling size for **site index studies** was restricted by the research permit. However, allocated site and sampling size permitted investigation of different site productivities. The dimension of the sampled trees differed between sites. The stands were also in different developmental stages. Sampled trees at HR and HS have not yet reached their final tree height. As a result, it was not possible to receive realistic asymptotic top heights from the fitted growth model.

The reference age of 30 years had to be set to allow for **site index comparison**. This restricted the predictive power of the study. In contrast, in North America reference ages of 50 years are widely used (MONSERUD, 1984; BIGING, 1985). The limits of the low reference age become apparent when comparing the site index curves of PC and HS. For further validation of the developed site index curves, sampling size and age of investigated trees has to be increased.

2.6.2 Interpretation of the results

2.6.2.1 Soil interpretation

Soil conditions were investigated as one approach to describe and distinguish site conditions in DDF. Neither soil type, texture nor nutrient status alone are sufficient to describe the variance between sites. However, PCA proved that clay and phosphorus content explain most of the variance between the investigated sites. Based on these parameters, the Cluster Analysis, detected the closest similarity between the two soil samples from HS. The HR and MN soil characteristics are not clearly different from these of the HS site.

The MN and HS sites can be distinguished by the phosphorus gradient, while clay content differentiated the HR site from the HS sites. The PC site was very different from all other sites due to calcareous parant material.

The soil type classification already predicted the results of the Cluster Analysis. The calceric cambisol site has distinctively different properties. The taxonomic grouping of the HR site into the Alisol group and the MN and HS site into the Arenosol group did not reflect major differences in soil quality. This taxonomic separation is principally based on a relatively small increase in clay content (SCHULTE & RUHIYAT, 1998).

As expected, soil parameters were significantly correlated with each other. However, some significant inter-correlation mentioned in other studies were not observed: organic matter and base saturation were significantly correlated in a study in India (SUJATHA & THOMAS, 1997), while significant correlation between phosphorus and organic matter, phosphorus and pH as well as an inverse correlation between organic matter and pH were detected during a study in Malaysia (TANGE et al., 1998). These differences might be attributed to the very different soil-types.

The susceptibility of soils with DDF coverage to erosion is marked. Even a slight increase in slope angle can result in top soil run off. For example at the upper slope HS1 profile, the sandy fluvial cover is still visible due to the gently sloping topography, while at the mid-slope HS2 profile, the fluvial material is already eroded. However the sandstone parant material underneath is less developed and leached, indicated by higher clay content beneath the top soil layer. This clay fraction is favourable for nutrient retention because it is relatively rich in three layered clay minerals (KUBINIOK, 1999).

The sandy soils at HS, HR and MN were strongly weathered and leaching occurred up to a depth of 40 cm. Clay content increased with depth.

Below, soil analysis results will be discussed and compared to specific sites:

- At the **HR** site, clay content, cation exchange capacity and organic matter of the topsoil were slightly higher than at HS. The higher clay content can be attributed either to the different parent material or to the leaching intensity. This could be explained by the fact that the forest compared to HS had been less disturbed by intensive forest interventions which had kept leaching affects to a minimum.
- From the two soil profiles at **HS**, the HS2 profile showed lower pH and base saturation, however organic matter, cation exchange capacity and phosphorus content were slightly higher. The differences between the upper slope profile (HS1) and the middle slope profile (HS2) may be attributed to the soil development stage (as explained previously) and the organic matter content. The increased cation exchange capacity can be attributed to the higher organic matter content, which almost entirely dictates the cation exchange capacity in leached tropical soils (GREENLAND, 1986).
- The **MN** site differs from HS1-2 and HR with respect to phosphorus and organic matter content between 5-60 cm soil depth. Phosphorus is very important for root growth and almost always limited in tropical soils (YOUNG, 1976; SCHULTE & RUHYAT, 1998). Organic matter is important for soil structure, nutrient and moisture retention. The higher phosphorus content in MN can be either explained by the occurrence of apatite (the principal source of phosphorus), by the higher amount of humus mineralisation (YOUNG, 1976) or by the fact that fire-induced phosphorus losses are less severe (SUKWONG & DHAMANITAYAKUL, 1977). The increased organic matter in the lower horizons might be due to the higher stand volume and lower degradation prevailing at the MN site. Also, organic content levels are higher in mature forests (BROWN & LUGO, 1990).
- Compared to other sites the nutrient content at the **PC** site was much higher. There, the main restrictions for growth were the high skeleton content (> 90 %). The phosphorus content was even lower than at the MN site and owing to the high pH in the soil horizons between 20-60 cm, the availability is poor and it quickly reverts to insoluble forms (YOUNG, 1976).

2.6.2.2 Vegetation interpretation

Vegetation analysis is generally a promising approach when used to distinguish certain site conditions. This in particularly useful as undergrowth tree and non tree composition are not influenced by selective cutting, so long as site and stand conditions remain constant, whereas canopy tree species composition varies with cutting. However, based on the available information, tree species proved to be more suitable to distinguish forest types because species occur more exclusively in one forest, as mentioned previously (ELLIOTT & MAXWELL, 1998).

The analysis showed that the MN and PC sites are richer in species occurring in evergreen forest and in particular in MDF, while the HS and HR sites are richer in DDF species.

The undergrowth tree species composition and the canopy trees indicate different forest types. Naturally, on limestone such as at the PC site, MDF would be expected (RUNDEL & BOONPRAGOB, 1995), however DDF canopy tree species occurred. The MDF species in the undergrowth indicate this site is suitable for MDF species to grow. Similar findings were made at the MN site.

Peculiarly *Xylia xylocarpa* was frequently present in the canopy, along with the dominant *Diperocarpaceae* species only in the MN and PC forest. This species seems to be typical for a transition forest between MDF and DDF. Overall, undergrowth tree species composition at MN was similar to the transitional forest type, as identified at Huai Kha Khaeng (FEHR, 1998; WEYERHÄUSER, 1998).

2.6.2.3 Site index interpretation

Site productivity based on *Vitex limoniifolia* stem section analysis was studied at all four sites. These sites can be ranked according to site index.

The MN site had the highest site index (SI 14.2 m) based on a reference age of 30 years, followed by the trees growing at the HR and the HS site (SI 9.6 m and 8.1 m, respectively). At PC site index was 6.9 m.

Compared to yield tables from teak plantation sites in northern Thailand, site productivity in DDF was relatively low as expected. In teak plantations, site index at the same reference age ranged from 10 to 30 years (SAHUNALU et al, 1992; CHALERMPONGSE, 1992).

It is obvious that the site conditions at MN represent the mesic, upper threshold of the investigated DDF sites. The main reason for the high site index value seems to be a combination of phosphorus availability and access to water long into the dry season. As the water is retained the undergrowth dries out later and consequently the fire season is delayed. Therefore fire events and associated impacts on site conditions (GIOVANNI, 1994; TENNIGKEIT, 1997; DE BANO et al., 1998) are reduced.

The other sites investigated differ from the MN site and showed lower site index values. At HS and HR, stands were relatively young, which limits index comparison to a reference age of 30 years. At this age the site indices of HR and HS were higher compared to PC.

At the PC site height growth cumulates at an age above 70 years, while at the MN site this is reached much earlier. At PC tree height development was lower but lasted longer. As a result, trees may reach similar top heights. Methods of entire height growth curve analysis (MCDILL et al., 1992) might be advisable to attain the whole growth function.

The lack of datable tree species is the single most important restriction for retrospective analyses of forest growth dynamics in the tropics. *Vitex limoniifolia* is the only species that develops annual growth rings and occur frequently in all deciduous forest types. Therefore *Vitex limoniifolia* is suitable for site index studies and growth response to climate investigations.

The study recommends analysis methods and provides information for site adapted forestry practices in Thailand. However, prior to large-scale implementation, more extensive sampling and verification of findings is advisable.

2.6.3 Conclusions

Finally the different site assessment approaches will be compared with each other. It was demonstrated that site quality can only be directly determined by soil surveys. The site index is the only parameter directly related to forest productivity. Indirect determination of site productivity based on vegetation and soil analyses is a potential approach, as long as the relationship with the direct parameters are clear. In Tab. 2.1 the different approaches were characterised and their application evaluated.

Tab. 2.1: Comparison between the applied site quality and productivity assessment approaches.

Criteria	**Site quality and productivity assessment approach**		
	Soil survey	Vegetation survey	Development of site index curves
Direct/indirect parameter for site quality	direct	indirect	indirect
Direct/indirect parameter for forest productivity	indirect	indirect	direct
Methodological restrictions	-top soil nutrient status is affected by recent fire events	-at present species indicator information is rare	-relies on stem section analysis, destructive method
Applicational restrictions	-soils with high skeletal content (> 90 %)	-where grazing takes place	-where growth information is not monitored and can not be reconstructed (e.g. datable trees are not abundant)
Necessary human skills and resources	-field work requires educational skills -soil analysis can be automated	-field work requires plant identification skills	-experienced human resources are advisable
Time and resource demand	medium	low	medium-high
Advisable approach for the following management objective	-plantation forestry	-conservation management -production of NTFP -community based timber production	-plantation forestry -large scale semi-natural timber production

As expected, site assessment approaches are restricted to certain site conditions. Also, the site assessment approach is influenced by the necessary information to achieve the management objectives.

- **Soil surveys** are useful for plantations, soil information is necessary because for irrigation and amelioration investments.
- **Vegetation surveys** are advisable where forest resources will be managed to provide NTFP and timber products for the local community, as this approach allows the local community to assess and monitor the resources on its own. As far as indicator species can be utilised, monitoring these species is of interest. For conservation management,

vegetation analysis can be used to describe the actual status of a habitat and to define management targets.

- **Site index studies**, based on growth monitoring or stem section analysis are a prerequisite to estimate sustainable harvesting quantities. However site conditions should be stratified and for each stratum site indices should be determined.

A combination of different site assessment approaches might be the most effective tools in many cases.

Restrictions exist due to limited information on:

- the relation between soil parameters and site productivity;
- species indicator values;
- minimal experience on how to establish site quality and productivity surveys.

These demand further research on this topic.

3 STAND STATUS AND DYNAMICS ASSESSMENTS

3.1 INTRODUCTION

In the previous chapter, site conditions of DDF were investigated and site productivity differentiated between the study sites. Of these four research sites, stand status and dynamics were studied to propose stand-adapted improvement treatment concepts at HR and HS, both stands are degraded by exploitation and fire.

In exploited forests, stand volume tends to be low, as only few large trees remain. These are often of undesirable quality and thus do not justify further investments. Consequently, improvement treatment concepts should focus on pole size trees and regeneration.

To date, there is only superficial knowledge on the dynamics of the degraded DDF (cf. Chapter 1.5.7). Therefore the diameter increment of adult trees was monitored annually, documenting species-specific growth patterns, while monthly measurements were undertaken on a small sample to detect seasonal growth patterns. Investigations of seedling development provided information on recruitment and mortality, as well as on early stand establishment.

Illegal timber utilisation is an important factor for the degradation of most DDF stands in Thailand. So far the impact of the intensive cutting on forest quality and species composition is unknown. Therefore, a stump survey was conducted to demonstrate cutting intensity, changes in species composition, stand quality and yield development.

3.2 RESEARCH OUTLINE

The research outline can be described in the following order:

- DDF attributes will be reviewed;
- the species composition will be analysed;
- results of stand structure analysis and diameter growth dynamics studies will be provided;
- effects of uncontrolled forest utilisation on stand basal area balance, species and diameter distribution will be investigated;
- stem quality will be considered.

3.3 REVIEW

3.3.1 Forest types in Continental Southeast Asia

3.3.1.1 Existing classification systems

Three distinct floristic elements exist in CSEA: the Indo-Burmese, the Indo-Chinese and the Malaysian (SMITINAND, 1980, 1992; ASHTON, 1990, 1995). The number of species found in a given area can be very high and the attempt to establish an holistic classification system is a difficult task.

Different classification systems can serve specific purposes (LAMPRECHT, 1990). They are differentiated according to their validity and their classification criteria into:

- global climate based classifications (HOLDRIDGE, 1967; WALTER & BRECKLE, 1984);
- global physiognomy based classifications (ELLENBERG & MUELLER-DOMBOIS, 1967; BRÜNIG, 1972);
- regional species community valid systems (AUBREVILLE, 1957).

With respect to CSEA a classification has yet to be accomplished (ASHTON et al., 1995), while for the whole of tropical Asia classifications exist (WHITMORE, 1988). Regionally, the forests of former Indo-China (VIDAL, 1956, 1959; ROLLET, 1972) and Myanmar were classified (TROUP, 1921; KERMODE, 1964; CHAMPION et al. 1965; CHAMPION & SETH, 1968a,b).

In Thailand, several attempts have been made to classify forest types (OGAWA et al., 1961; KÜCHLER & SAWYER, 1967; SANTISUK, 1988 and SMITINAND, 1992). Two classification systems have been developed more specifically for northern Thailand (SANTISUK, 1988; MAXWELL et al., 1995; ELLIOTT & MAXWELL, 1998).

3.3.1.2 Deciduous forest types

Mixed Deciduous Forests (MDF) succeeded teak (*Tectona grandis)* forests, after large scale commercial logging in northern Thailand eliminated or reduced teak to a minor component of the forests. Today, teak forests survive only in small patches, such as in the National Parks bordering Myanmar and the Mae Yom National Park (BROCKELMAN, 1994).

In MDF, the main canopy trees are up to 30 m high. Deciduous trees comprise more than 80 % of the individuals. Fire return intervals are generally very long. Usually the forest grows on loamy, deep soils, both of limestone and granite origin. The Chiang Mai University herbarium database recorded 150 MDF tree species. In this forest type, no single species reaches dominance. Some valuable commercial tree species like *Xylia xylocarpa*, *Dalbergia fusca*, *Pterocarpus macrocarpus* and *Afzelia xylocarpa* are present. Other typical species of low commercial value are *Terminalia chebula*, *T. mucronata*, *Schleichera trijuga*, *Sterculia pexa* and *Spondias pinnata*.

Deciduous Dipterocarp-Oak Forests (DDF) succeed MDF after stand degradation or grow, where poor and shallow soils prevail. The undisturbed vertical DDF structure can be characterised by a single tree, shrub and seedling layer (KÜCHLER & SAWYER, 1967; SUKWONG, 1974). The canopy is never dense and trees reach heights between 8 and 25 m (BUNYAVEJCHEWIN, 1983a,b). However, trees rarely exceed heights of 20 m. An estimated 86 % of tree species are completely deciduous (ELLIOTT & MAXWELL, 1998). The *Dipterocarpaceae* species *Dipterocarpus obtusifolius*, *D. tuberculatus, Shorea obtusa*, *S. siamensis* dominate. Other characteristic tree species are *Quercus kerrii*, *Castanopsis diversifolia*, *Lithocarpus elegans* and *Ochna integerrima* (MAXWELL et al., 1995, 1997). Also common are *Buchania lanzan, B. glabra, Craibiodendron stellatum, Eugenia cumini, Dalbergia fusca*, *Gluta usitata*, *Tristaniopsis burmanica, Strychnos nux-vomica* and *Anneslea fragans* which are also found in other forest types (ELLIOTT & MAXWELL, 1998).

Where fire occurs annually, oak is rare or absent. Also, oak suffers the most from selective felling, due to its high timber value. In western Thailand, oak does not occur, even in undisturbed forests (FEHR, 1998; WEYERHÄUSER, 1998).

Savannah Forests are the most extreme form of DDF in Thailand (SMITINAND, 1992). Trees are scattered, tree heights are between 10-15 m. Thus, the definition of Savannah Forest for a relative vigorous DDF in the Huai Kha Kaeng Wildlife Sanctuary by STOTT (1988) seems misleading.

Savannah Forests occur on poor, shallow soil, similar to DDF. Precipitation is often as low as 500 mm per annum. Thus, forest fires are frequent in this forest type. Tree species found in Savannah Forests such as *Careya arborea*, *Mitragyna parvifolia* and *Ochna spp.* are fire resistant.

3.3.2 Community structure

3.3.2.1 Species richness and composition

The total number of species per hectare is highly correlated to the forest type and its present quality, its homogeneity level and past human influence. Species richness decreases if site conditions become more xeric (FEHR,1998; WEYERHÄUSER, 1998).

In DDF across Thailand, 103 tree species were recorded (NEAL, 1967) with a DBH of ≥ 4.5 cm. Results of further studies are displayed in Tab. 3.1. However, they are difficult to compare because some results represent species richness of single study areas (KIRATIPRAYOON et al., 1995; FEHR, 1998; WEYERHÄUSER, 1998), while other results were based on pooled surveys from several different areas (ROLLET, 1972; BIOTROP, 1976, 1977; LY VAN HOI, 1952, cited in BLASCO, 1983).

Tab. 3.1: Results of selected studies in Thailand, Laos and Cambodia investigating species richness in DDF.

Woody species	Reference area ha	Country	Source
103	2	Thailand	NEAL, 1967
Between 8-22	0.2	Thailand	BIOTROP, 1976, 1977
66	1	Thailand	KIRATIPRAYOON et al., 1995
58	1.2	Thailand	FEHR, 1998; WEYERHÄUSER, 1998
135	73	Southern Laos	LY VAN HOI, 1952, cited in BLASCO 1983
82	46	Eastern Cambodia	ROLLET, 1972

Extensive surveys were made in DDF in eastern Cambodia, where sampling size was 46 hectare and 82 tree species with a DBH ≥ 4.5 cm were recorded (ROLLET, 1972). In Laos, 135 species occurred on 73 hectare DDF (LY VAN HOI cited in BLASCO, 1983).

Species composition was investigated in three DDF in the Prom Basin, Thailand (SAHUNALU & DHANMANONDA, 1995). There, Shannon diversity indices between 1.8 and 3.0 were recorded.

3.3.2.2 Horizontal stand structure

Stem density and basal area are inversely related in DDF (BUNYAVEJCHEWIN, 1983b; RUNDEL & BOONPRAGOB, 1995), particularly in the most xeric areas where DDF and

Savannah Forests prevail. In Tab. 3.1, stand structure parameters of a DDF shrub type are compared with a vigorous DDF medium tall *Shorea obtusa* type.

Tab. 3.1: Stand structure parameters of DDF (BUNYAVEJCHEWIN, 1983a,b).

Parameter		DDF *Shorea siamensis* shrub subtype		DDF *Medium tall Shorea obtusa* sub type	
Basal area	m^2 ha^{-1}	10	± 3.5	18	± 5
Stems (≥ 4.5 cm DBH)	stems ha^{-1}	602	± 385	440	± 140

The canopy layer may become discontinuous in DDF, reflecting the light patterns. Generally the stand crown projection area covers less than 70 % of the ground surface in DDF (SUKWONG, 1974).

Stem-DBH distribution patterns of DDF in Thailand and Laos show that in this forest type tree densities decrease moderately towards DBH maximum values of 75 cm (Fig. 3.1).

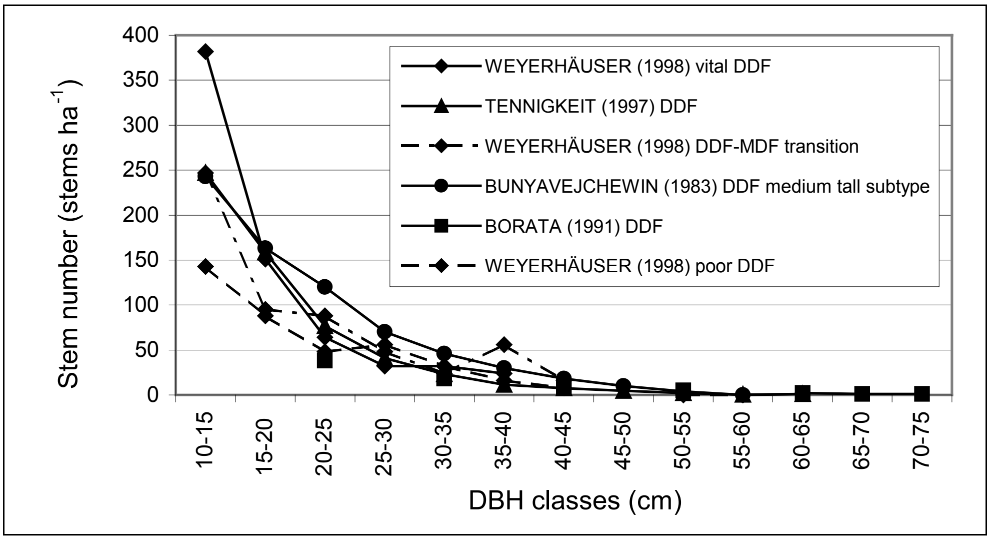

Fig. 3.1: DBH distribution of DDF in Thailand and Laos.

It should be noted that the actual reference area from BORROTA (1991) was 108 ha. The results from BUNYAVEYCHEWIN (1983b) and TENNIGKEIT (1997) are based on a reference area of 2 ha. The 2 DDF stands investigated by WEYERHÄUSER (1998) represent a sample area of 0.2 ha each.

3.3.3 Stand dynamics

3.3.3.1 Diameter growth development

The annual DBH increment was recorded between 1995 and 1999 in different DDF types in western Thailand (WEYERHÄUSER, 1998). The annual median DBH increment was 0.1 cm y^{-1} for ***Ster****eospermum* ***neur****anthum* and 0.2 cm y^{-1} for the two predominant *Dipterocarpaceae* species ***Shor****ea* ***siam****ensis* and ***Shor****ea* ***obtu****sa* (see Fig. 3.1).

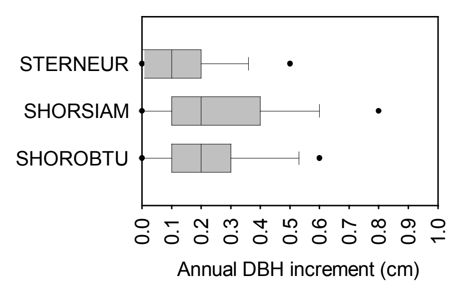

Fig. 3.1: Median representation of annual DBH increment between 1995 and 1999 of trees from the three dominant DDF species (WEYERHÄUSER, 1998 and unpublished data).

Dots represent the 5th and 95th percentiles; whiskers the 10th and 90th percentiles and the box the 25th and 75th percentiles around the central tendency.

Species codes: ***STER**eospermum* ***NEUR**anthum*, ***SHOR**ea* ***SIAM**ensis*, ***SHOR**ea* ***OBTU**sa.*

In DDF, DBH increment is zero for several trees in every year. The median representation demonstrates that in 25 % of *Stereospermum neuranthum* trees, no increment was recorded, while just 5 % zero growth measurements of *Dipterocarpaceae* trees were recorded during the five years investigated.

In the same study, the **basal area increment** was determined. In 1996 it was between 2.4 and 5.5 %, in 1997 between 1.6 and 2.5 % and in 1998 and 1999 between 3 and 4 % (WEYERHÄUSER, 1998).

Monthly and seasonal growth patterns seem to be correlated to precipitation. DBH increment, observed between 1974 and 1975, started in May after the first rains and ceased after the rain season (SUKWONG et al., 1975). However, unexpectedly, pronounced stem shrinking was observed in January 1975, in the middle of the dry season. Diameter growth of *Dipterocarpus alatus,* recorded in west Thailand in 1995, started before the rainy season and stopped at the end of August, two months earlier than the end of the rainy season (TANAKA et al., 1996).

3.3.3.2 Regeneration

Vegetative regeneration is particularly pronounced under dry and arid conditions, where fires occur and where grazing is an important component (KERMODE, 1964). Certain families exhibit striking tendencies to reproduce vegetatively, for example *Leguminosae, Rosaceae*, *Dipterocarpaceae* and *Bignoniaceae* (TROUP, 1921; SUKWONG, 1974).

The ability to produce new shoots from below ground is referred to as seedling coppice (CHAMPION et al., 1968a). This feature is common to some deciduous tree species, for example *Dipterocarpaceae, Tectona grandis, Pterocarpus macrocarpus.* Young shoots may re-sprout for many years, gradually developing a thickened root stock (SETH & KHAN, 1960). Accumulated nutrients enable emerging shoots to grow vigorously, eventually allowing shoots to outgrow the lethal fire zone in a single season or a short sequence of few fire-free seasons (SUKWONG & DHAMANITAYAKUL, 1977; SMITINAND, 1980). If light is sufficient shoots can grow very fast (CHAMPION et al., 1965). SUKWONG et al. (1977) noted growth rates for *Dipterocarpaceae* species of 65 cm within two months in the first year after coppice. However, subsequent growth slows down and regeneration of seeds may catch up after a number of years (CHAMPION et al., 1968a). Irrespective of the season, even in the dry season, many species respond to damage with vigorous seedling coppice (TENNIGKEIT, 1997).

Generative regeneration in DDF suffers from short fire intervals. The deciduous *Dipterocarpaceae* species produce a certain quantity of seeds every year while mast years occur at frequent intervals (TROUP, 1921). Seeds of deciduous *Dipterocarpaceae* species are short lived (FEHR, 1998). Subsequently, one pre-condition for germination of such species is that seeds are ripe in a period when climatic and site conditions are favourable, for example after the fire season and in time for the first rains. The seeds of many other species ripen toward the end of the growing season and then remain on the tree until site-conditions are favourable for example *Pterocarpus macrocarpus* (FEHR, 1998). Alternatively, many species of *Leguminosae*, *Nelumbiaceae* and *Malvaceae*, particularly those with hard shells, may contribute to the seed-bank and stay dormant in the soil for years (CHAMPION et al., 1965, CHAMPION & SETH, 1968a). They will only germinate when conditions are suitable, mostly linked with the first rains (STOTT, 1988). Two widely quoted examples are *Tectona grandis* and *Cassia fistula* (TROUP, 1921; KERMODE, 1964).

Different soil treatments such as the removal of competing ground vegetation, increased germination and survival rates of *Pterocarpus macrocarpus* and *Dalbergia cultrata* significantly (GOTZEK, 1999).

3.3.3.3 Progressive and regressive succession

In CSEA, fire is the most decisive successional factor and has shaped the landscape for millennia (STOTT, 1988).

Following forest exploitation, the canopy is less dense and the undergrowth dries out. In this condition, the forest is much more susceptible to fire. Fire-induced regressive succession leads to a considerable increase of fire-adapted DDF communities. With the exclusion of fire, forest formations rapidly progress (FEHR, 1998). The high proportion of mixed deciduous species found in the regeneration stage of DDF (KUTINTARA & BHUMPAKKAPUN, 1989; KIRATIPRAYOON et al., 1995; MAXWELL et al., 1995; FEHR, 1998) may indicate the re-commencement of successional processes after a period of fire-conditioned regression.

Under the repeated influence of fire, a given forest formation tends to disintegrate until savannah forests and later grasslands prevail (BLASCO, 1983). Fire-conditioned regressive successions are particularly rapid and evident where hygrophilous and evergreen forest-formations prevail. Here, fires have an immediate detrimental affect since few species are adapted to fire. Similar processes can result from intensive and continuous grazing. The consequence of this regressive succession is that many former evergreen forests and MDF in northern Thailand degraded to DDF today. The persistence of lichen species in DDF, that are usually associated with semi-evergreen communities, also indicate these successional dynamic (WOLSELEY & AGUIRRE-HUDSON, 1991).

In summary, the different deciduous community-types are the physiognomic expression of degree and frequency of fires and subsequent stand depletion (BLASCO, 1983).

3.4 MATERIAL AND METHODS

3.4.1 Sampling design

The status of the two research stands at HR and HS was investigated between December 1997 and April 1998. On these sampling plots, silvicultural improvement treatment variants were applied afterwards. The site conditions at HR and HS were already described in Chapter 2. The exact location of the study plots is presented in Appendix 1.

To permit comparison between silvicultural treatment variants and previous research in Thailand, plot-size was set to 1,600 m^2 and the sample plots were placed in the most homogenous stands available. The silvicultural treatment variants will be introduced in Chapter 4.

At HR, a total of 12 sample plots were set up to test three treatment variants, each replicated three times for statistical evaluation and compared to three control plots. The treatment design was similar at HS, however four silvicultural improvement treatment variants could be set up and as a consequence 15 sample plots were considered during stand investigations.

Plot placement occurred in homogenous parts of the forests. Plots were sited preferably in 6 plot blocks to minimise variance between silvicultural treatment replications (see Appendix 2). At HS, plots 1-9 were set up in two strips (3 and 6 plots).

Block or strip designs were also considered most appropriate to keep the amount of fire breaks to a minimum. Given the climatic conditions, fire breaks were absolutely essential. Breaks, 4 m wide, were laid out around each block or stripe. Fire lines were cleared of dry leaves weekly during the dry season. Nevertheless at HR 2 plots burned in 1998 and all 12 plots were burned in 1999. At HS, 3 plots burned in 1998 and 8 plots in 1999.

In both stands investigated, a similar inventory design was applied (see FEHR, 1998). Within a given plot all adult trees were recorded. Saplings and seedlings were sampled in systematically distributed sub-plots (see Fig. 3.1 and Tab. 3.3).

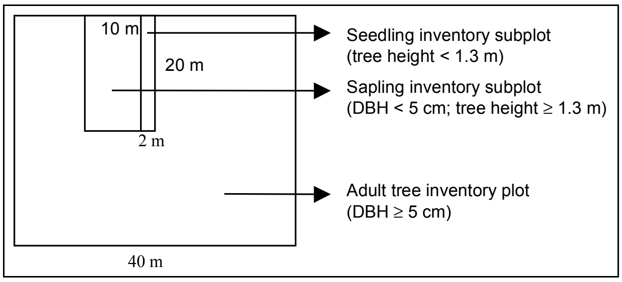

Fig. 3.1: Inventory plot design.

Tab. 3.1: Inventory design and definition of the tree development stages.

Tree strata	Definition	Plot numbers and dimensions		Total sample area	
		HR (12 plots)	HS (15 plots)	HR	HS
		m		m^2	
Adult trees	DBH $\geq$ 5 cm	40 x 40	40 x 40	19,200	24,000
Saplings	DBH < 5 cm, tree height $\geq$ 1.3 m	10 x 20	10 x 20	2,400	3,000
Seedlings	Tree height < 1.3 m	2 x 20	2 x 20	480	600

All adult trees received a numbered aluminium label, placed at eye level, facing towards the base line of each plot. The corners of the plots were marked permanently (iron pegs). In addition, near each corner three prominent trees were marked with paint and their angle and distance to the corner peg recorded. Similarly, sapling and seedling plots were marked and protected from disturbance during inventory work.

3.4.2 Investigated tree parameters

Each individual sampled in any of the three sampling strata was identified and its height and relative horizontal position measured:

- Species, identified in the field, were cross-checked by the herbarium curator of the Biology Department at Chiang Mai University. The species specimens were deposited at the Silviculture Research Centre in Chiang Mai.
- Seedling position and height were measured using a metal tape.
- In the adult tree and sapling tree strata, tree heights were determined using a Suunto digital hypsometer.

3.4.2.1 Population characteristics

Besides these general parameters collected in all strata, for each stratum a number of specific parameters were sampled:

- DBH was measured for adult trees and saplings, to the nearest millimetre. Stem quality was recorded.
- For seedlings, the number of coppice shoots in a cluster were counted.
- In the sapling plots, the results of illegal cutting activities were traced. The position of remaining stumps, their basal diameter and the species and stump age were determined (LÖTSCH, 1958; BOONYOBHAS, 1961). Stump age was estimated by the degree of wood decay by two independently working sampling teams. This cross-checking came up with similar results. Stumps could be identified if cutting took place less than 10 years ago. However, due to nearly annual dry season fires, the stumps of soft wood species are burned earlier than others. It is probable therefore that the investigated cutting intensity represents an underestimation.

3.4.2.2 Crown parameters

Crowns of adult trees were characterised by:

- heights of the first dead branches and first living branches;
- crown radii measurements along cardinal axes;
- the social position according to crown light availability (see Tab. 3.1).

Social position	Definition in relation to light
5	Crown in full overhead and lateral light
4	Crown in full overhead light, lateral shade
3	Crown partially exposed to overhead light, lateral shade
2	Crown without overhead light, partially shaded
1	Crown shaded on all sides, no direct light

Tab. 3.1: Social position based on crown classification (DAWKINS, 1958).

3.4.2.3 Tree quality

On the basis of tree condition features, quality was determined and distinguished in three grades (see Tab. 3.1).

Tab. 3.1: Tree quality grades.

Quality grade	Definition
1	Trees of high quality. Boles straight, no visible stem damage, saw-wood quality.
2	Trees of average quality. Small fire scars at the base of the trees, slightly twisted or bent boles. Envisaged products could be low quality construction timber.
3	Trees of low quality. Large fire scars, bent and forked, often both occurring together, with life expectancy uncertain, fuel-wood quality.

3.4.2.4 Forest dynamic measurements

Diameter dynamics were investigated on a monthly and annual basis.

With the onset of the experiments in April 1998, diameter development was monitored to the nearest millimetre at HS on a monthly basis until November 1999, to investigate seasonal growth patterns. Readings were taken always on 15th of each month. To this end increment tapes were fixed at 30 selected trees of four most frequent tree species. During measurements 13 tapes were either damaged or disappeared. For seasonal growth monitoring, trees of social position three or four (see Tab. 3.1) with favourable crown forms were chosen. To exclude age-dependent growth affects (age estimated by DBH), the sampling stratum was homogenised, only trees with a DBH between 8 and 16 cm were considered.

The diameter of the whole adult tree stratum was re-measured twice at HR and HS, during the second and third field season in December 1998 and 1999. Similarly, seedling height, mortality and recruitment was monitored.

3.4.2.5 Species diversity measures

Indices of species diversity serve to describe the stands and their dynamics. They commonly take into account species richness and evenness (MAGURRAN, 1988). The following indices were used.

Species-area curves

Species-area curves describe the relationship between species occurrence in relation to sampling intensity. It is an estimate of the representation of the flora in a given survey. A common practice is to randomly arrange the plots and to display the results as a cumulative function. On the basis of 100 randomly generated repetitions cumulative curves were calculated separately for the different tree strata, for both the HR and HS stands.

Sörenson's similarity index

Similarity indices measure the degree to which the species compositions are alike (KENT & COKER, 1995). This index was explained in Chapter 2.4.3.2.

Shannon diversity Index

The Shannon index (H') is a widely used measure of diversity. The formula to calculate the index is:

$H' = - \sum_{pi} \ln {}_{pi}$, where pi is the proportional abundance of the ith species =(ni/N) (MAGURRAN, 1988). The index increases with increasing species richness and species diversity. The highest values (H_{max}) reflect situations where all species are equally abundant. Index values usually range from 1.5 to 3.5 (KENT & COKER, 1995). The ratio of observed to maximum diversity can therefore be taken as a measure of evenness (J') (PIELOU, 1984).

The index assumes that individuals are randomly sampled from an infinitely large population (PIELOU, 1984). It is also assumed that all species of a community are represented in the sample (KENT & COKER, 1995). This increases errors if the proportion of species represented in a sample is small.

For calculating the Shannon index, every logarithm may be used as long as it is applied consistently. Data analyses were based on the natural logarithm.

3.4.2.6 Light measurements

Light is one of the main tree growth factors. In order to investigate the impact of light on regeneration and to assess the light variability between the plots, light conditions were estimated for each plot by two hemispherical photos taken within the seedling plot. Photos were taken at 1.3 m with a fish eye lens vertical into the sky, covering an angle of nearly 180°. Photo analysis and interpretation was conducted according to BRUNNER (1998).

Photographs were digitised and analysed on a pixel basis. A threshold to transform individual pixel grey values into black and white (canopy/sky) was set visually after comparing the results of different threshold values. Estimates on diffuse and direct Percent Above Canopy Light (PACL) were calculated using additional information on sun position within the calculation period. The calculation period in temperate forests is normally identical with the vegetation period. In the applied context, PACL was calculated for the period between 1st May and 14th November. There was no meteorological information available on the proportion of diffuse and direct sunlight, therefore an equal share was anticipated.

3.5 RESULTS

3.5.1 Species composition

Overall 45 tree species occurred in both stands. Species richness was approximately comparable between the investigated stands in the adult tree and seedling strata (Tab. 3.1). However, in the sapling stratum species richness was markedly lower at HS.

Tab. 3.1: Tree species richness in different tree development strata.

Tree species richness	HR		HS	
Overall tree species	40	species 2.4 ha^{-1}	39	species 1.92 ha^{-1}
Adult trees (DBH ≥ 5 cm)	36	species 1.92 ha^{-1}	36	species 2.4 ha^{-1}
Saplings (height ≥ 1.3, DBH < 5 cm)	27	species 0.24 ha^{-1}	20	species 0.3 ha^{-1}
Seedlings (height < 1.3 m)	30	species 0.048 ha^{-1}	27	species 0.06 ha^{-1}

Tree density in the sapling and seedling strata was lower at HS but similar in the adult tree stratum as displayed in Tab. 3.2.

Tree strata abundance	HR Individuals ha^{-1}	HS Individuals ha^{-1}
Adult trees	1,750	1,800
Saplings	2,350	1,400
Seedlings	18,000	11,500

Tab. 3.2: Tree abundance in different tree development strata.

The two stands also differed with regards to species composition (Fig. 3.1 and Fig. 3.2). While the adult tree and sapling tree strata is dominated by species of the *Dipterocarpaceae* family, in the seedling stratum species abundance is less dominated by this family.

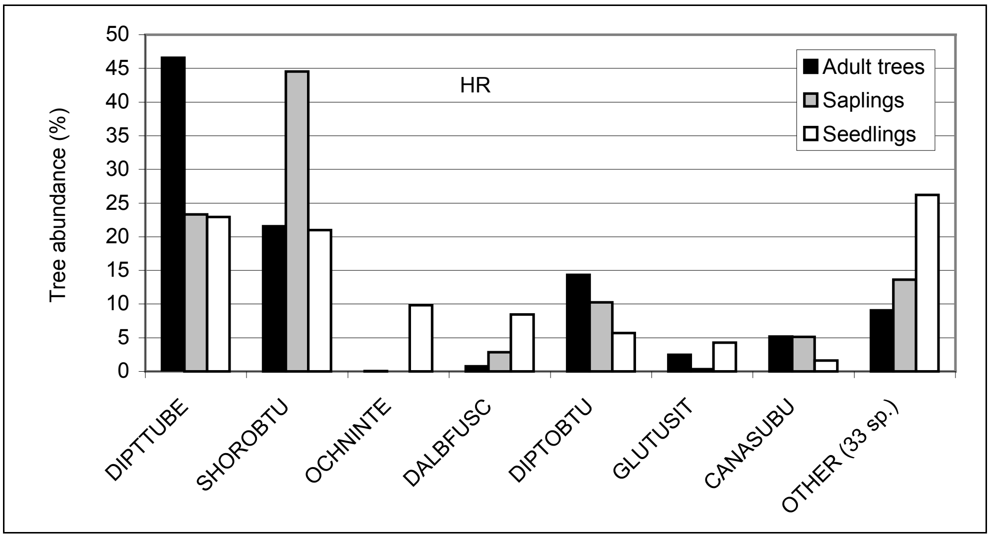

Fig. 3.1: Relative abundance of the four most frequent species of each tree class and the cumulated remaining species in each development stratum at HR in 1997.

Species codes: ***DIPT**erocarpus* ***TUBE**rculatus*, ***SHOR**ea* ***OBTU**sa*, ***OCHN**a* ***INTE**gerrima*, ***DALB**ergia* ***FUSC**a*, ***DIPT**erocarpus* ***OBTU**sifolius*, ***GLUT**inosa* ***USIT**ata*, ***CANA**rium* ***SUBU**latum*

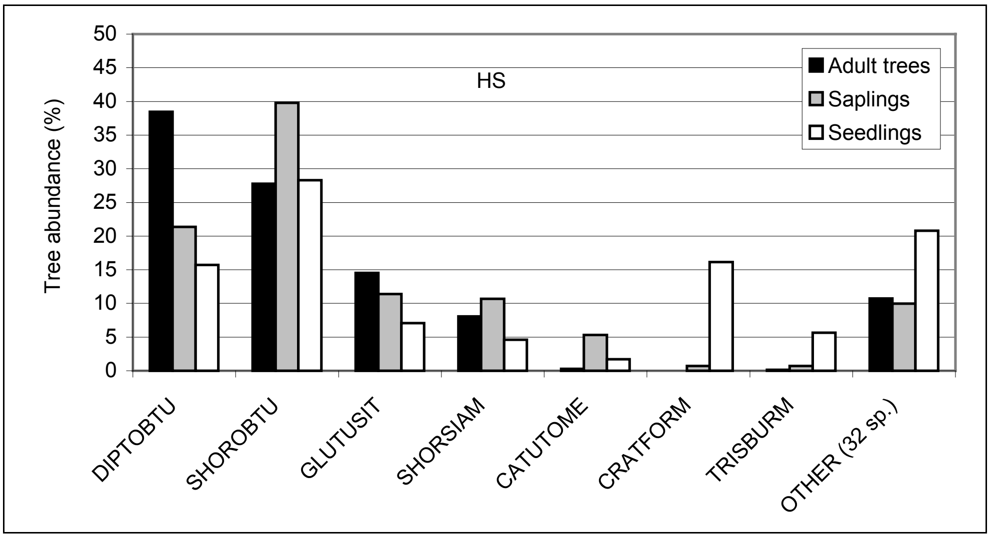

Fig. 3.2: Relative abundance of the four most frequent species of each tree class and the cumulated remaining species per tree development stratum at HS in 1997.

Species codes: ***DIPT****erocarpus* ***OBTU****sifolius,* ***SHOR****ea* ***OBTU****sa,* ***GLUT****inosa* ***USIT****ata,* ***SHOR****ea* ***SIAM****ensis,* ***CATU****naregam* ***TOME****ntosa,* ***CRAT****oxylum* ***FORM****osum,* ***TRIS****taniopsis* ***BURM****anica*

In the adult tree stratum, *D. tuberculatus* and *S. obtusa* represented more than 60 % of the trees at HR. At HS, *D. tuberculatus* was substituted in this dominant position by *D. obtusifolius*.

S. siamensis was not abundant at HR in the adult tree stratum, however it was relatively abundant in the sapling stratum in both stands. Seedlings of the early pioneer species *Ochna integerrima* and *Cratoxylum formosum* occurred frequently in both stands. In HR the frequency of *Dalbergia fusca* seedlings is pronounced. Species abundance of all species is presented in Appendix 9.

3.5.2 Species diversity

In both stands, the highest species diversity occurred in the seedling stratum (Tab. 3.1). The lowest values occurred in the adult tree stratum. Calculated diversity values in the seedling stratum are also closest to approach maximum diversity values, attributable to the high evenness values.

Tab. 3.1: Tree diversity indices: Shannon (H') and Evenness (J').

Index	HR			HS		
	Adult trees	Saplings	Seedlings	Adult trees	Saplings	Seedlings
H'	1.79	1.85	2.54	1.73	1.86	2.36
H' max	3.61	3.26	3.37	3.58	3.00	3.30
J'	0.50	0.57	0.75	0.48	0.62	0.72

3.5.3 Sörenson's similarity index

The computing of the Sörenson's similarity index indicated that HR and HS stand species were roughly equal (similarity index 0.86). Between the sapling strata of HR and HS lower species similarity values were found (similarity index 0.61).

3.5.4 Species area curves

The cumulative species area curves for the adult tree and seedling strata start to level off at around 10 sample plots (Fig. 3.1), thus the area sampled is sufficient to represent the prevailing species. In contrast, the curves for the HR sapling stratum do not level off, an indication of inadequate sample numbers.

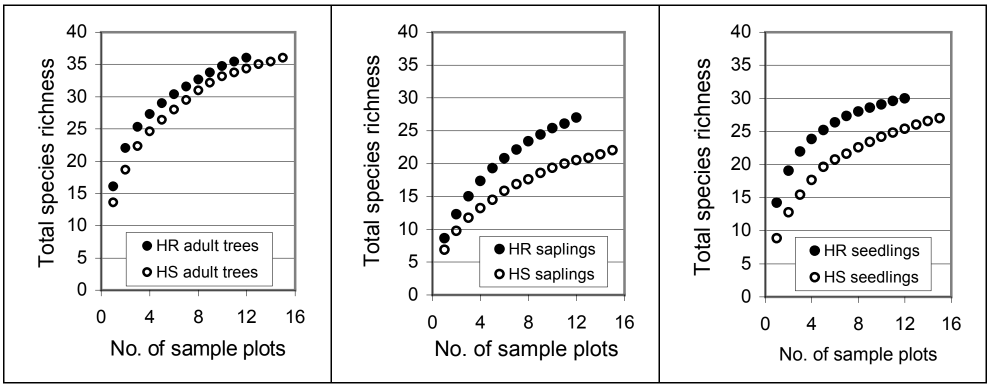

Fig. 3.1: Cumulative species area curves at the HR and HS stands: adult trees, saplings and seedlings.

3.5.5 Adult trees

3.5.5.1 Stand structure

Both stands at HR and HS were relatively young. More than 90 % of all trees had a DBH between 5 and 15 cm, with the exception that at HR a few residual trees with undesirable bole forms of larger dimension remained. The strongly "L"-shaped DBH class distribution as visible in Fig. 3.1 is an indication of the small stand volume. Trees with a DBH over 30 cm hardly exist.

At HS, almost no residual trees in greater DBH classes prevailed. The DBH class distribution is also strongly "L"-shaped.

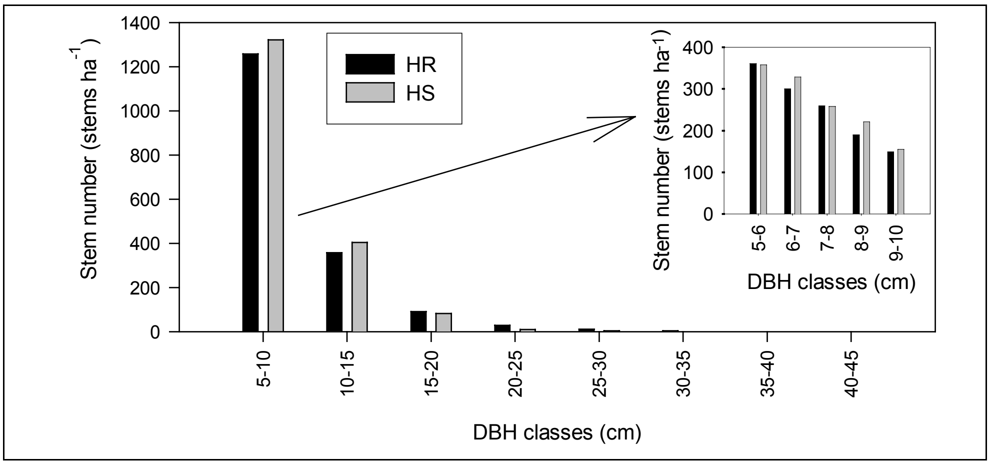

Fig. 3.1: DBH distribution between 5-10 cm and across all DBH classes at HR and HS in 1997.

Top height (mean height of the 100 trees per hectare with the largest basal area) was 7.5 m at HR and 6.5 m at HS. The maximal tree height reached 20 m at HR, 14 m at HS (Fig. 3.2).

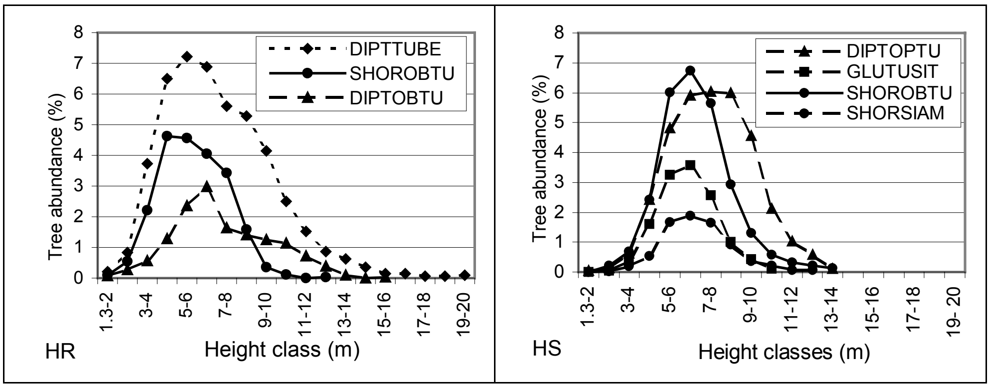

Fig. 3.2: Height-class specific abundance of selected trees ≥ 5 cm DBH.

Species codes: ***DIPT**erocarpus **TUBE**rculatus, **SHOR**ea **OBTU**sa, **DIPT**erocarpus **OBTU**sifolius, **GLUT**inosa **USIT**ata, **SHOR**ea **SIAM**ensis*

At HR, the abundance curves rapidly approach peak tree heights between 4 and 7 m and then taper off asymetrically, while the height class distribution of HS follow a Gaussian distribution. Consequently, the height class curve of the HR stand has a wider base than that of the HS stand. The tree heights of the *D. tuberculatus* remainder trees at HR exceeded all trees of other species.

3.5.5.2 Basal area and stand volume

The basal area and the stand volume for the investigated stands in 1997 are displayed in Tab. 3.1. Basal area and stand volume were higher at HR.

Stand	Basal area m² ha^{-1}	Stand volume m³ ha^{-1}
HR	13.9	50.8
HS	12.3	41.1

Tab. 3.1: Basal area and stand volume at HR and HS in 1997.

Tree volume (solid volume over bark) was calculated with the following volume function $V=g_{1.3}h\ f$ ($g_{1.3}$ as the basal area at 1.3 m; h as the tree height and f as the false form quotient). A false form quotient of 0.4 is used in northern Thailand for DDF stands of a mean DBH between 5-15 cm (PUNCHAI, 1999).

3.5.5.3 Horizontal tree distribution

The scattered tree distribution of 6 representative study plots each for HR and HS are displayed in Fig. 3.1. At HR, stem clusters were less pronounced compared to HS. Trees of greater diameter were more abundant and loosely spread over all plots at HR.

The horizontal stem distribution is relatively even on either stand. The few greater dimensional trees clustered at two plots, where stem density was relatively low.

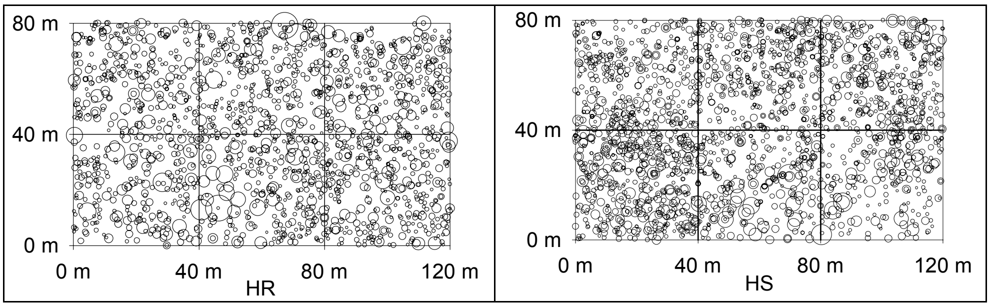

Fig. 3.1: Tree distribution of the selected plots at HR and HS.

6 plots of each stand were plotted by their X and Y co-ordinate. Circle size is related to DBH.

3.5.5.4 Monthly diameter development at HS

Monthly readings of the installed diameter tapes provided information of the diameter development during the annual growth circle (see Fig. 3.1). In 1998 and 1999, most trees started growth between June and July and lasted until October-November. A similar trend could be confirmed for most trees. Some *D. obtusifolius* and *S. obtusa* trees showed zero annual increment in the 1998 growing season.

Between December and January, a diameter decrease was observed for more than 50 % of the trees. *Dalbergia fusca*, known for rapid tree growth in early years, showed much higher growth rates than any of the *Dipterocarpaceae* species individuals, even under poor site conditions, such as at HS.

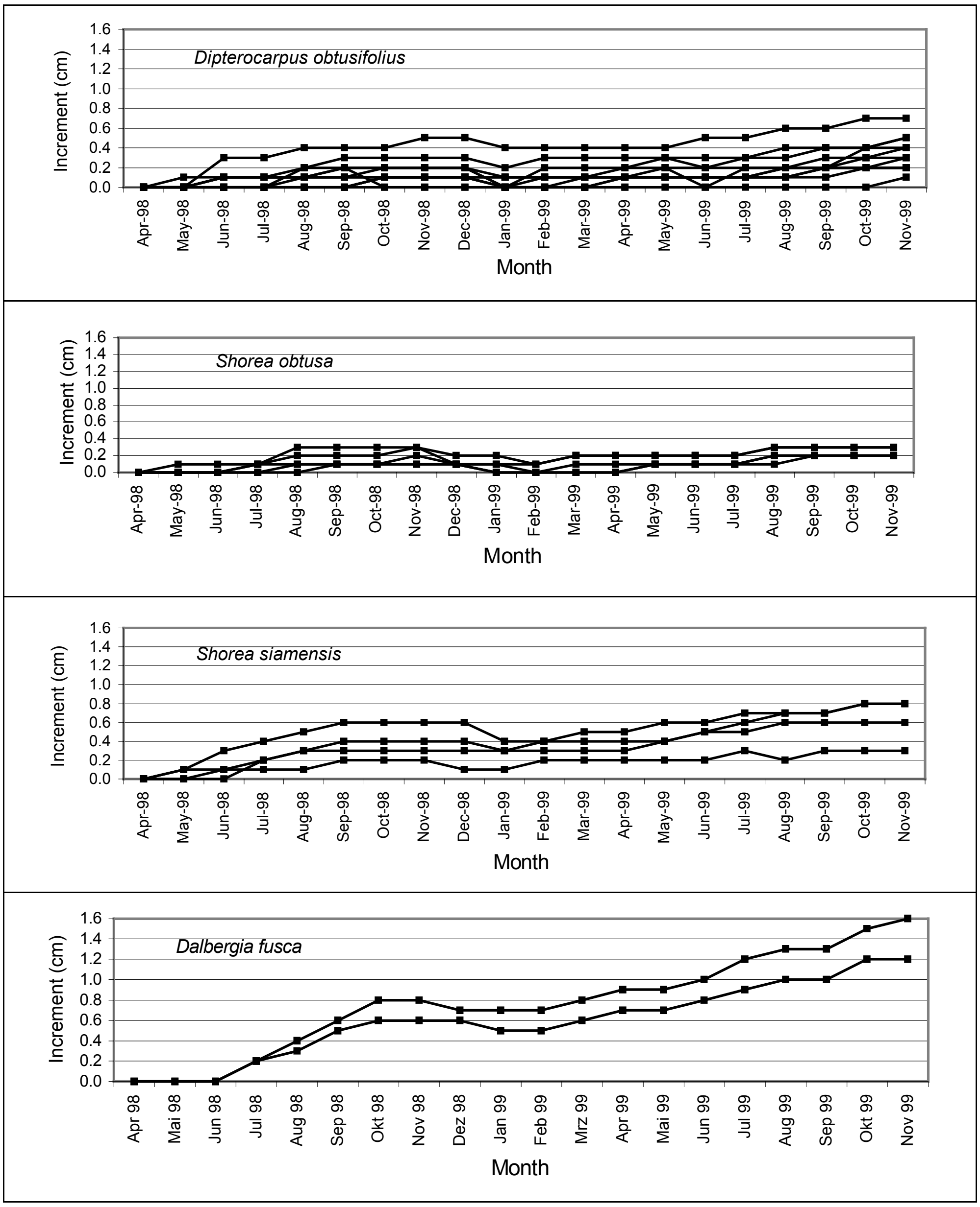

Fig. 3.1: Monthly DBH increment of selected trees recorded between April 1998 and November 1999 at HS.

3.5.5.5 Annual species specific diameter development

Similar to the monthly diameter development, the annual increment rates proved to be different between species (Fig. 3.1).

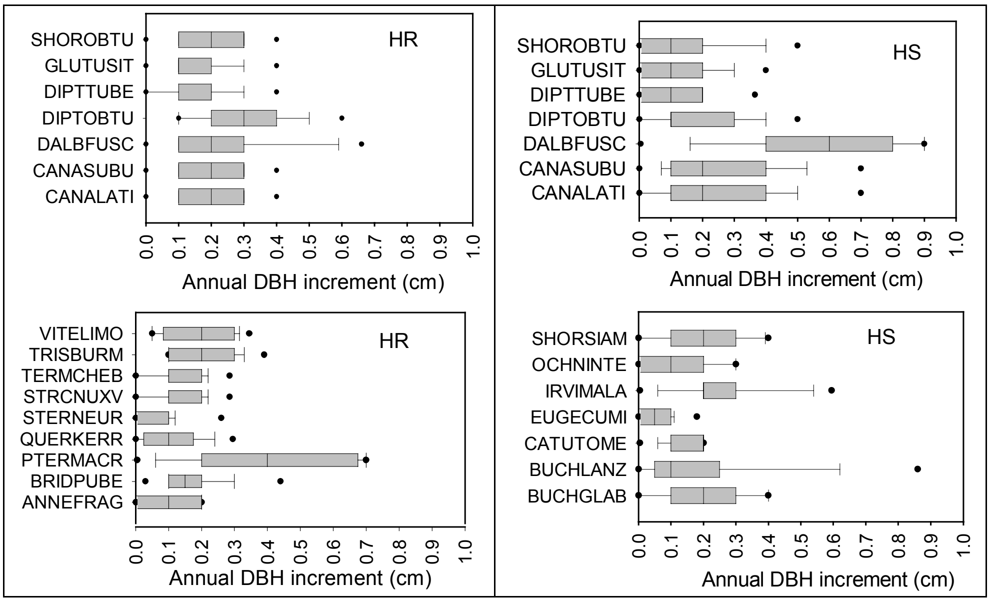

Fig. 3.1: Annual DBH increment values of selected species individuals in 1998 and 1999 at HR and HS.

Dots represent the 5th and 95th percentiles; whiskers the 10th and 90th percentiles and the box the 25th and 75th percentiles around the central tendency. For species codes and sampling size, see Appendix 8-9. Only species with individual abundance ≥ 10 per research stand were considered.

DBH increment, averaged across all species, was higher at HR. Exceptionally high annual increment rates, between 1997 and 1999, were observed for *Pterocarpus macrocarpus* at HR, with a median increment value of 0.4 cm y^{-1}. *Dalbergia fusca* showed good growth performance on either stand. However, it was the only species where the median DBH increment was higher at HS (0.6 cm y^{-1}) compared to HR (0.2 cm y^{-1}). The stand dominating *Dipterocarpaceae* trees achieved median annual growth rates between 0.1 and 0.3 cm y^{-1}. *D. obtusifolius* and *S. siamensis* showed better growth performance than *S. obtusa* and *D. tuberculatus*.

Zero growth was recorded in 5 % of the observations for nearly all species that occurred on both stands (except *D. obtusifolius*).

The **basal area increment** at HR in 1998 and 1999 was 6.3 and 6.8 % respectively (see Tab. 3.1). At HS the basal area increment was lower. Notable for the HS stand is also the higher variance between the increments in 1998 (1.9 %) and 1999 (4.8 %).

Tab. 3.1: Basal area development at HR and HS in 1998 and 1999.

Site	Basal area in '97	Basal area development in '98		Basal area development in '99	
	m^2 ha^{-1}	m^2 ha^{-1}	%	m^2 ha^{-1}	%
HR	13.9	14.8	6.3	15.8	6.8
HS	12.3	12.5	1.9	13.1	4.8

3.5.6 Saplings

Due to the regular occurrence of fires, few seedlings reached the sapling stage. At HR 1,700 saplings per ha were distributed over a small tree height range, mainly between 1.3 m and 3.0 m (Fig. 3.1). The 1,400 saplings per ha at HS were more evenly distributed along the tree height classes. A gap between 2.5 and 3 m was common to both research stands.

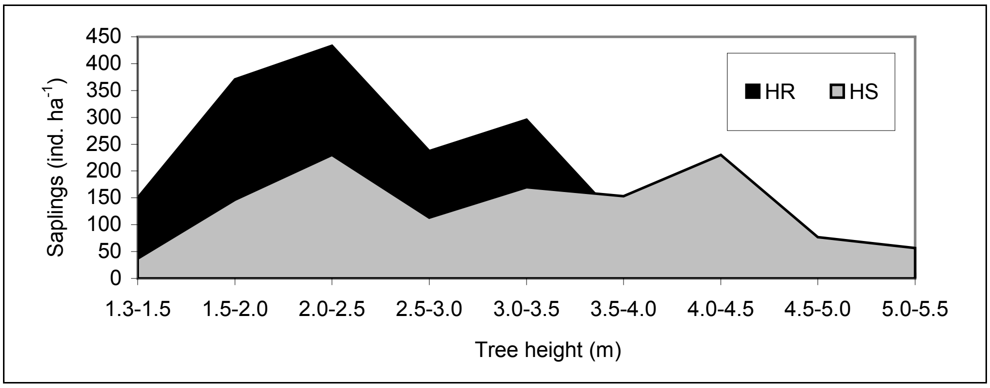

Fig. 3.1: Sapling height abundance at HS and HR in 1997.

The scatter plot in Fig. 3.2 displays sapling height to DBH. It shows that saplings with a DBH less than 5 cm can reach tree heights up to 5.5 m. The widespread values of *S. obtusa* saplings contrasts with the high regression coefficient received between *D. obtusifolius* sapling height and DBH.

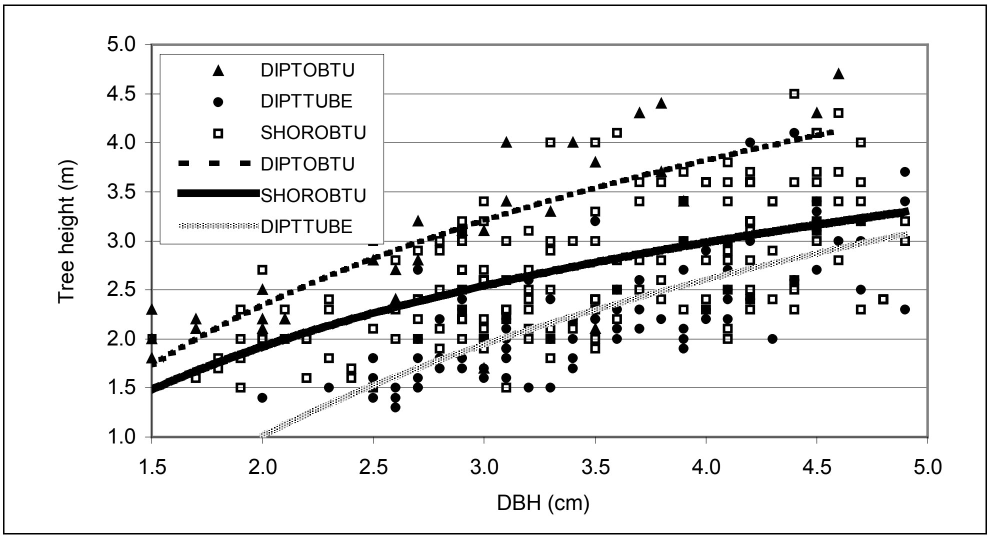

Fig. 3.2: Relationship between sapling DBH and height in 1997 for selected species at HR.

For species codes see Appendix 8. Logarithmically fitted curves based on hyperbolic functions: *D. obtusifolius* (R^2= 0.7; 40 saplings), *D. tuberculatus* (R^2 = 0.6; 83 saplings), *S. obtusa* (R^2 = 0.4; 184 saplings).

3.5.7 Seedlings

3.5.7.1 Seedling dynamics and the impact of forest fires

The height class-specific seedling abundance at HR follows a negative exponential distribution pattern. At HS the distribution is best approximated by a negative sigmoidal distribution (Fig. 3.1). Here, the seedlings in the smallest height class were under-represented, while seedlings between 30-40 cm were over-represented.

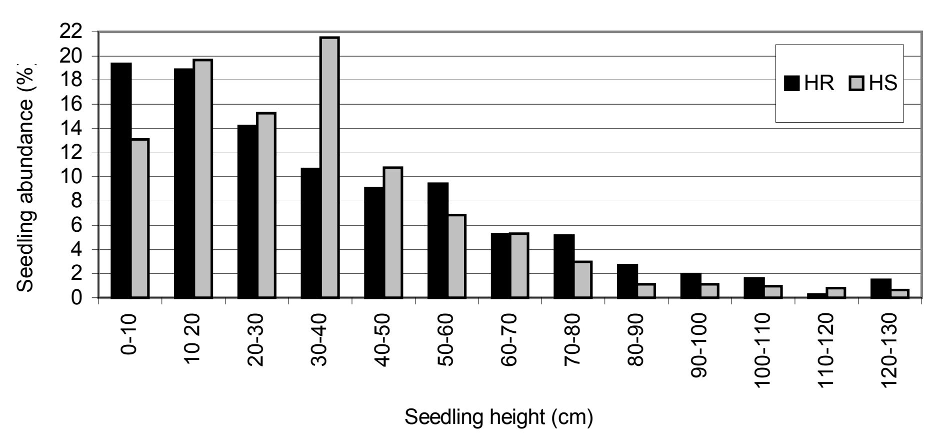

Fig. 3.1: Relative height class-specific abundance of seedlings.

Recruitment and mortality rates demonstrate fluctuations between 4 and 19 %. (see Fig. 3.2). Most study plots showed approximately balanced recruitment and mortality rates.

Fig. 3.2: Recruitment and mortality rates at HR and HS between 1997 and 1999 in relation to the fire regime on the plots.

Read fire regime codes b/ub/b as follows: the box presents mortality and recruitment rates in 1999. The plot was **b**urned in 1997, **unb**urned in 1998 and again **b**urned in 1999.

Only in the plots successfully fire protected in 1998 and burned in 1999 (b/ub/b), recruitment and mortality rates were not balanced. Here mortality rates were 19 % at HR and 10 % at HS, compared to the recruitment rates of 8 % at HR and 4 % at HS. Recruitment tends not to be stimulated by fire. Of the abundant species, only *Dalbergia fusca* seedlings regenerated much better after fire. On the other hand fire exclusion did not have a clear affect on mortality rates.

Annual seedling growth rates in 1998 and 1999 of selected species at HR varied, depending on species and fire regimes. Median increment values between 10 and 70 cm y^{-1} (Fig. 3.3) were recorded.

As displayed, seedlings of three out of five selected species *D. obtusifolius, Dalbergia fusca* and *S. obtusa* showed superior growth performance within the two investigated years.

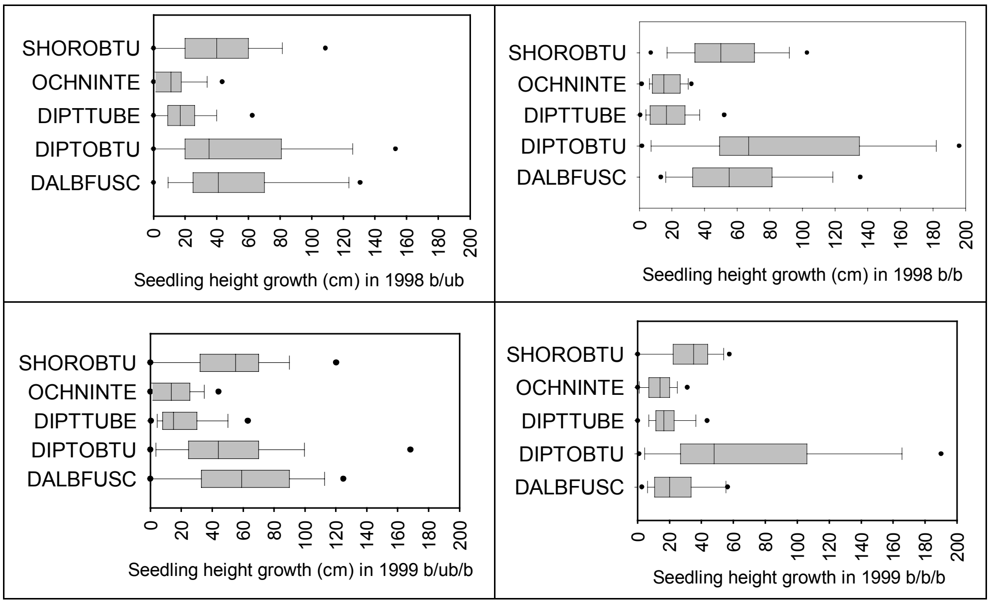

Fig. 3.3: Annual seedling height growth in 1998 and 1999 of the five dominant seedling species at HR in relation to fire regime.

Read fire regime code b/ub/b as follow: **b**urned in 1997, **unb**urned in 1998 and again **b**urned in 1999. Dots represent the 5th and 95th percentiles; whiskers the 10th and 90th percentiles and the box the 25th and 75th percentiles around the central tendency. For species codes see Appendix 8.

Seedlings burned in February 1998, when compared to the unburned seedlings of the same species, demonstrated better growth rates the following year (refer to Fig. 3.3 left and right column in the first row).

In 1999, however, when all plots burned at HR and new sprouts came up, the fire protected seedlings during the previous season showed superior height growth (refer to Fig. 3.3 second row).

3.5.7.2 Effects of light conditions on seedling dynamics

Light measurements at HR and HS recorded that nearly 40 % of the mean total canopy light was available at 1.3 m. Throughout the 30 sample points at HS, 24 at HR, the light variability was rather low. The mean differences between total maximum and minimum light values was 19 and 27 % at HR and HS respectively.

Similar to the low light variability between plots, light variability within plots was also low. Significant relations between light availability and seedling height growth could not be detected neither on the burned plots, nor on the unburned plots at HR and HS.

On the unburned research plots at HR there seemed to be a trend that sprout cluster size and light availability were inversely related to each other. This means that with increasing light, the amount of sprouts per cluster is decreasing. This relation was most strongly visible for *D. tuberculatus* seedlings. Here a regression coefficient of 0.7 was detected. In the HS stand, due to the less favourable site conditions, light may not be able to influence the number of sprouts.

3.5.8 Effects of uncontrolled forest utilisation

3.5.8.1 Quantification of uncontrolled forest utilisation

Between 1994 and 1997, at HR an average of 80 trees $ha^{-1}y^{-1}$ were cut. The cutting intensity at HS was lower with 29 trees ha^{-1} y^{-1} (see Tab. 3.1). This can be attributed to poor accessibility of the stand and to the presence of a forest guard station nearby. Further away from the guard station, intensive cutting activities as in HR were observed.

Tab. 3.1: Average annual cutting rate measured in stump abundance of main tree species and in relation to total adult trees.

Species	**Stumps** ha^{-1} y^{-1}		**Stumps in relation to total adult trees** %	
	HR	HS	HR	HS
Dipterocarpus tuberculatus	31	0	4	0
Shorea obtusa	29	7	8	1
Dipterocarpus obtusifolius	14	18	6	3
Other species	5	4	2	1
Total	**80**	**29**	**5**	**2**

At HR a higher proportion of *S. obtusa* and *D. obtusifolius* trees were felled while *D. tuberculatus* trees, a less valuable timber tree, was relatively under-utilised. The preference to cut tree species of high economic value was visible at HS as well.

At HR the average annual cutting rate yielded between 1995 to 1997 was about 70 trees ha^{-1} y^{-1}. In 1994, the cutting rate exceeded 100 trees ha^{-1} y^{-1}, while before 1994 the investigated annual cutting rate was lower (Fig. 3.1).

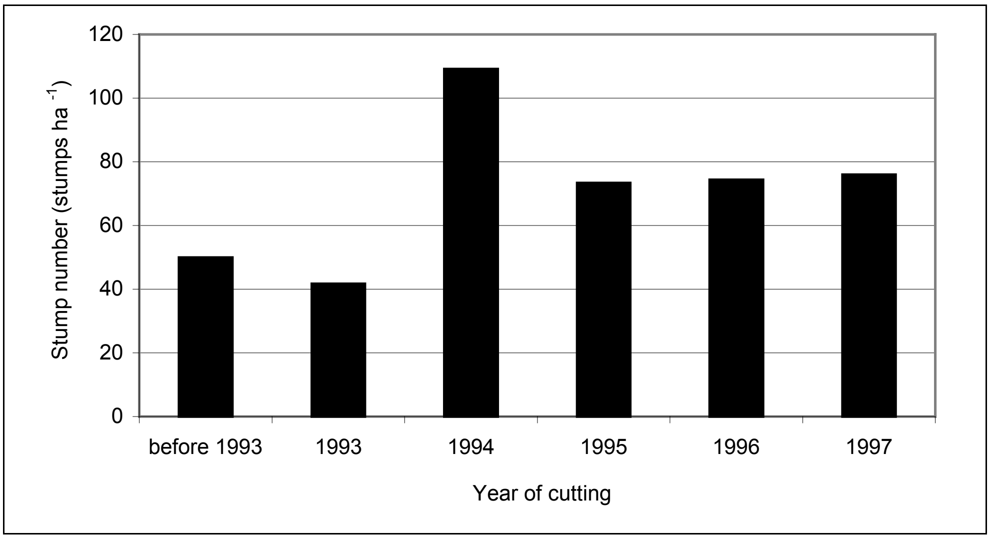

Fig. 3.1: Stump counts at HR - 1993 to 1997.

The comparison between the stand DBH distribution and the basal stump diameter distribution (see Fig. 3.2) showed that 70 % of all stumps at HR and nearly 50 % at HS had a basal diameter between 5 and 15 cm. The stand DBH distribution explains why the extracted amount of medium size timber was very low, because, very few trees of that dimension occurred and in addition these were predominantly of poor quality.

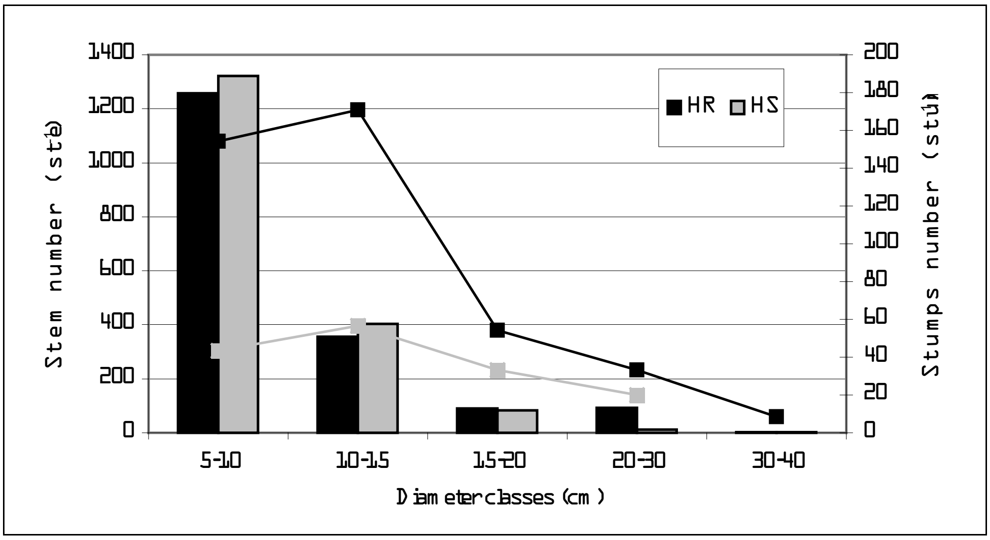

Fig. 3.2: Comparison between DBH class distribution of standing trees (bars) and the basal stump diameter distribution (lines).

Note: Differences in diameter class ranges!

3.5.8.2 Basal area balance

The basal area balance (see Tab. 3.1) is the balance between the average annual basal area reduction due to cutting and the basal area increment as investigated for 1998 and 1999 (compare Tab. 3.1). The comparison demonstrates that across all species the basal area reduction and increment were approximately balanced.

Stand	Basal area reduction	Basal area increment	
		1998	1999
	%	%	%
HR	5.9	6.0	6.3
HS	3.8	1.9	4.8

Tab. 3.1: The relation between basal area reduction and increment.

Based on the average timber extraction rate between 1993 and 1997 the basal area was computed at DBH over bark. The calculation of the annual basal area reduction was based on stump basal diameter measurements under bark.

The periodical basal area increment was considerably higher at HR. Accordingly, the local residents extracted more timber.

3.5.8.3 Tree quality analyses

At the HR and HS stands, less than one third of all trees were graded into quality class one 56 and 42 % of the trees respectively belonged to the quality class 3 (Fig. 3.1), such as were suited for firewood only. More trees were graded to quality class 3 and less to quality class 1 at HR. On both sites trees of minority species were of even poorer quality.

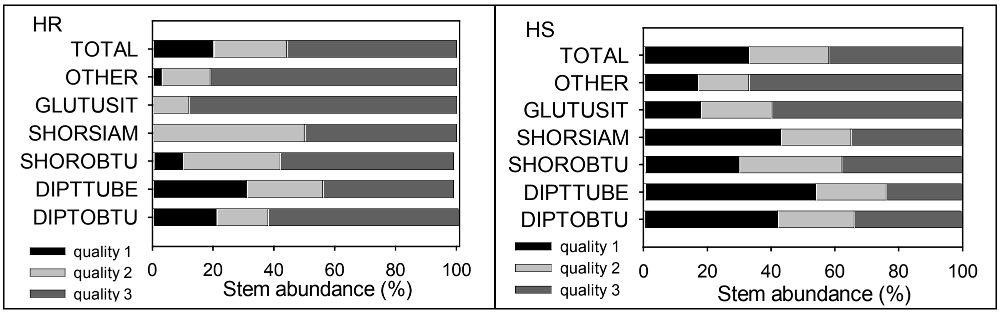

Fig. 3.1: Tree quality classification.

For species codes see Appendix 8.

At HR, approximately 60 % of all trees were bent at least once (Fig. 3.2). *D. obtusifolius* had the highest relative bent stem proportion with 68 %. All stems had less bents at the HS stand were 17 % of the trees were bent. Aside from this, 8 % of all stems at HR and 13 % of all trees at HS were forked, mainly at a height between 1.5 and 3 m.

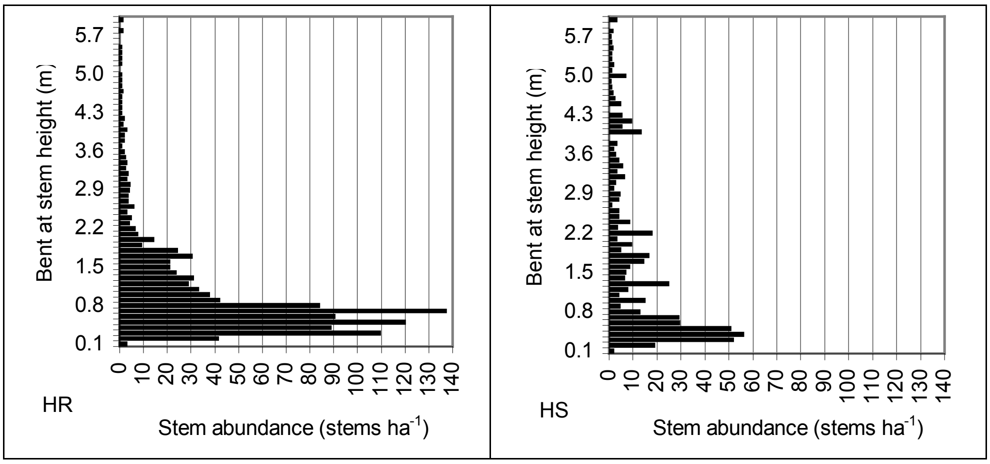

Fig. 3.2: Stem bends in relation to stem height.

The proportion of trees with stem foot damage was also considerably higher at HR. 21 % of all trees had stem foot damage at HR, compared to 6 % at HS (Fig. 3.3). The proportion of damaged *Glutinosa usitata* and *S. siamensis* trees was particularly marked.

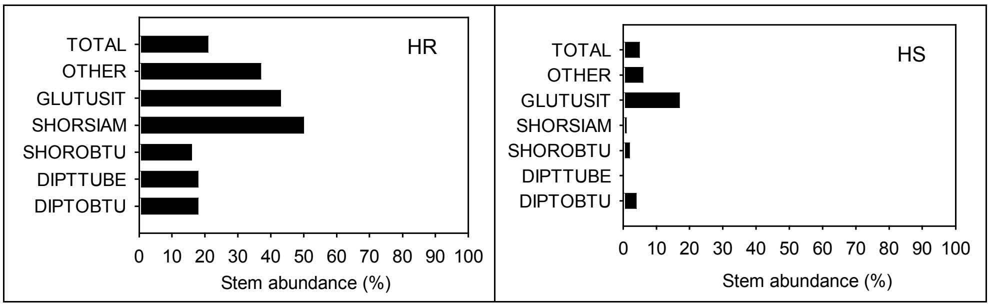

Fig. 3.3: Abundance of stem foot damage.

For species codes see Appendix 8.

3.6 DISCUSSION

3.6.1 Material and methodological aspects

A comparison of this research material with other studies is rather difficult as previous studies were performed on undisturbed forests under better site conditions.

For example, the last intensive national ground survey inventory on intact DDF in northern Thailand found that 40 % of trees ≥ 10 cm DBH with a DBH between 10-30 cm and another that 40 % had a diameter varying between 30-50 cm (BIOTROP, 1976, 1977). In Cambodia about 90 % of the trees had a diameter between 10-30 cm on 46 ha (ROLLET, 1972). Compared to the Thai and Cambodian inventories, the investigated stands here lack substantial diameters. The most probable explanation for this finding is increased logging (see Chapter 3.5.8) and different site conditions (see Chapter 2).

Sampling intensity was high (see Chapter 3.5.1) compared to these previous studies. As discussed in Chapter 3.5.4 an increase in the sampling intensity results in an increase in species richness. The species area curves derived from this sample show that not all the potential species were found. For a complete assessment of species richness sampling design should be changed.

The tree seedling dynamics observed were massively disturbed by frequent fires. Investigations of seedling dynamics in response to light were not possible as light variability was too low. This arose from the choice of similar light conditions for exclude the light parameter from comparison of the improvement treatment variants (see Chapter 3.4.1). To investigate the seedling response to different light conditions, stands with a high light variability should be chosen. Therefore it would be advisable to stratify stands according to canopy cover and to place sampling points in each stratum.

Basal area development estimated on annual diameter measurements in DDF has to consider a) seasonal trunk shrinking and swelling (SUKWONG, 1975; TANAKA et al., 1996) b) low increment values leading to relatively high increment measurement errors and c) the possibility of no annual diameter increment of some trees in this forest type. To circumvent these problems, permanent diameter measurement tapes were installed and monthly measurements conducted to investigate these fluctuations.

The basal area balance calculations were conducted using base diameter as the basis for the basal area reduction through cutting, while the increments were based on DBH measurements. This leads to an overestimate of the annual basal area extraction. However, the bark was missing on several stumps older than two years, which helped to reduce this error.

Annual timber utilisation estimations can be subject to considerable discrepancies. However, cross checking by two independent sampling teams received only minority discrepancies between the estimates. Investigations are more likely to underestimate utilisation intensity as stumps of softwood species may have dematerialised already.

3.6.2 Interpretation of the results

Species composition interpretation

On both stands studied adult tree, sapling and seedling species richness was low. Overall not more than 45 tree species occurred, while in a smaller DDF sampling size in west Thailand, 58 adult tree species with a DBH greater than 5 cm occurred (FEHR, 1998; WEYERHÄUSER, 1998). This could reflect the difference between intact and degraded DDF. In all studies, the highest species richness was recorded for the adult tree stratum, the lowest for the sapling stratum. These findings would contradict hypotheses which attribute the decreased species richness, specifically of the sapling strata, in degraded forests to logging and frequent fires.

The species diversity in both stands investigated was higher in the seedling stratum compared to the sapling and adult tree strata. Higher species diversity for adult trees were recorded in a forest in northern Thailand. There adult tree diversity was H' = 2.2, compared to 1.79 at HR and 1.73 at HS. This particular forest was protected from fire and logging for 30 years (KAFLE, 1997). Considerably higher species diversity values were found in a secondary forest in northern Thailand due to high eveness (KIRATIPRAYOON et al, 1995). From this it can be concluded, that species diversity alone is not an indicator for stand disturbance.

There is debate over why the *Dipterocarpaceae* species still retains its dominance in the adult tree stratum in this study (Chapter 3.5.1). This dominance was also observed in a forest protected for 30 years (KAFLE, 1997). Thus, even if the forest is protected from fire and logging for a long time the *Dipterocarpaceae* species are still dominant in DDF.

Why other species do not occur more frequently in DDF is still unknown. The observed growth pattern of minority tree species like *Dalbergia fusca* and *Pterocarpus macrocarpus* demonstrate that these species can compete with the *Dipterocarpaceae* species. It is most likely that human impact, fire and selective cutting are detrimental to these valuable minority tree species.

This could be demonstrated by the analysis of the selective cutting activities (Chapter 3.5.8). At HR the more valuable *Dipterocarpaceae* species, *Shorea obtusa* and *Dipterocarpus obtusifolius* were over-utilised. It is likely that the actual disribution of valuable species like *Dalbergia fusca, Pterocarpus macrocarpus* and *Quercus kerii* is a result of long term, value driven selective cutting. These forestry practices have led to decreasing species diversity.

In this study, *Dipterocarpus obtusifolius* was the dominant species at HS and *Dipterocarpus tuberculatus* at HR. Preference for these species was previously attributed to elevation (OGAWA et al.,1961; BUNYAVEJCHEWIN, 1983a,b), site moisture (BUNYAVEJCHEWIN, 1983a,b) and the presence of laterites (TROUP, 1921; SMITINAND et al., 1980; BUNYAVEJCHEWIN, 1985). However, this study could not confirm these hypotheses. At HR *Dipterocarpus obtusifolius* was selectively over-utilised, compared to *Dipterocarpus tuberculatus*, as documented by the stump survey (Chapter 3.5.8). Thus human influence overrules the natural distribution of DDF species.

Stand structural interpretation

A single-storied canopy existed at HS, with the typical bell-shaped tree height distribution for young stands, which is similar to the natural, undisturbed DDF stand structure. At HR, the tree height distribution was not bell-shaped, due to the remaining trees of larger dimension.

Stem density (stems ≥ 5 cm DBH) was very high (HR, 1,750 stems ha^{-1}; HS, 1,800 stems ha^{-1}) compared to other studies with 700 and 900 stems ha^{-1} (FEHR, 1998; WEYERHÄUSER, 1998).

However, basal areas were only 13.9 m^2 ha^{-1} at HR and 12.3 m^2 ha^{-1} at HS. This is rather low compared with other studies where the basal area was between 12.5 and 20 m^2 ha^{-1} (KUTINTARA, 1975; DHANMANONDA, 1995; WEYERHÄUSER, 1998) and may indicate the high utilisation intensity. The low stand volume, 50.8 m^3 ha^{-1} at HR and 41.1 m^3 ha^{-1} at HS and the fact that 90 % of the trees have a DBH between 5-15 cm is a further characteristic of these stands.

The low sapling abundance and their poor quality is, aside from low adult tree quality, the most crucial factor for any type of stand improvement. This can be mainly attributed to the frequent fires, preventing the seedlings to grow into saplings (SUKWONG & DHAMANITAYAKUL, 1977; TENNIGKEIT, 1997).

Seedling density with 18,000 seedlings ha^{-1} at HR and 11,500 seedlings ha^{-1} at HS was abundant. However, this was low when compared to relatively undisturbed DDF in a Wildlife Sanctuary in west Thailand, with a seedling abundance between 25,000 and 50,000 ha^{-1}, measured for several years (FEHR, 1998). Outside this Wildlife Sanctuary, where the forest is more disturbed, seedling abundance was between 15,000 seedlings ha^{-1} on a site annually affected by forest fires and 30,000 seedlings ha^{-1} where the forest was protected from fires for three years (TENNIGKEIT, 1997). Another study conducted in central Thailand found 7,000 seedlings ha^{-1} on an annually burned plot, while a comparable 10 year fire protected DDF had a lower abundance with 5,500 seedlings ha^{-1} (SUKWONG & DHAMANITAYAKUL, 1977).

From these surveys it can be concluded that seedling abundance fluctuates from stand to stand and particularly between different years (FEHR, 1998). Fire protection did not necessarily increase seedling abundance. However, for sufficient seedling establishment fire protection is necessary (SUKWONG & DHAMANITAYAKUL, 1977; SUTTHIVANISH, 1989; SUNYAARCH, 1989), at least until the regeneration grows beyond the fire affected zone (SMITINAND, 1980; TENNIGKEIT, 1997).

Growth dynamic interpretation

The basal area increased in 1998 and 1999 by 6.3 and 6.8 % at HR and by 1.9 and 4.9 % at HS. In contrast to HS, at HR diameter increment of the main species did not suffer severely from the particularly dry year 1998.

These results compared well with the other studies conducted. Growth monitoring in northern Thailand recorded annual basal area increments between 5 % and 7 % (SAHUNALU & DHANMANONDA, 1995). Increments were between 2.5 % and 5 % in west Thailand, monitored over four years (WEYERHÄUSER, 1998; unpublished data).

On the species level, *Dalbergia fusca* showed the best growth performance in both investigated stands. It is surprising that this species has not been considered for forest plantations in Thailand. *Dalbergia sissoo*, another species in this family, attracts increasing attention in forest plantations in India and Nepal (SAH, 1999). The growth performance of *Pterocarpus macrocarpus* was promising as well. The favourable growth and the high timber value of this species was recently recognised in Thailand. Initial trials to promote this species for forest plantations were successful (BHODTHIPUKS, 1998). *Dipterocarpus obtusifolius* has the most promising growth performance of the main DDF species.

The diameter increment had a median between 0.1 and 0.3 cm y^{-1} across all dominant DDF species. This is relatively low when compared to a study in deciduous forests in Venezuela where mean annual DBH increment was 0.35 cm y^{-1}, (VEILLON, 1983 cited in LAMPRECHT, 1990). The diameter increment is clearly restricted by soil conditions as the precipitation at the two research sites was similar, but the stand DBH increment was higher at HR. The increment in 1998 compared to 1999 might be attributed to the low amount of rainfall in 1998 (Fig. 2.2).

Seedling growth rates were higher in 1999, where precipitation was increased compared to 1998. Seedling growth at HR was also generally more vigorous. Seedling mortality and recruitment rates in 1998 and 1999 was nearly balanced. Nevertheless it was recognised that after one year of fire protection, seedling mortality increased after the forest fire event, while the recruitment rate remains constant. This might be attributed to the fact that after one year of fire protection, seedlings are more sensitive to forest fires. The annual seedling gains and losses differ between species. This is because some regenerate under certain site conditions successfully and have a low mortality rate, whereas other species did not regenerate and have a high mortality rate. Exceptionally high mortality and recruitment rates as mentioned for *Shorea obtusa* (FEHR, 1998), could not be detected for any species.

Utilisation practices

The quantification of the uncontrolled forest utilisation provided valuable information on utilisation intensity, diameter and species preferences. The extracted diameter range may be an indication of the dominant diameters or an expression of the product demand at village level. The preference to cut trees with small diameters may be explained by the ease of cutting and transport and by the scarcity of larger-size, healthy trees. For charcoal production, stem diameters below 10 cm are preferred. Approximately one charcoal pit per hectare was found in HR and in the surrounding forest area (about 40 ha). Active pits were evenly distributed over the area. Despite the logging ban adopted in 1989, the demand of fuel and construction wood has not abated. In addition, the authorities will not prosecute if the extracted timber does not exceed about 0.2 m^3 - the approximate amount that can be carried on a motorcycle.

The increase in utilisation intensity since 1994 may be connected to the expansion of the nearby village, compounded by to the shrinking forest cover and the subsequent increase in pressure on the remaining forests.

Aerial photographs also provided information on stand utilisation intensity at HR and HS. At HS on aerial photographs from 1954 the forest canopy appeared to be relatively close, while on photographs from 1969 the forest cover was relatively open. Heavy forest exploitation took place in the intervening years. Since this intervention, timber utilisation seemed to remain constantly on a low level until recently. Aerial photographs from consecutive years at HR did not show such clear differences. It seems that continue intensive selective cutting over decades, rather than sporadic heavy exploitation, has promoted the dominance of the less valuable *Dipterocarpus tuberculatus*. Due to the poor quality of the aerial photographs the stand development could not be reconstructed sufficiently. However, studies into the historic stand development were influential for the interpretation of the actual tree diversity and stand structure (see above).

Stem quality

Stem quality in the adult tree stratum has to be considered as poor. Stem bends appear to result from poor cutting practices or from insect attacks. Stem damage due to insect attack to the terminal sprouts was noted only for *Shorea obtusa* trees (TENNIGKEIT, 1997). When terminal sprouts die off, lower branches take over the role of the terminal sprout. How far the resulting bend will straighten afterwards remains undetermined. In HR, nearly two-thirds of the remaining stumps had heights between 0.2 m and 0.6 m. After cutting, new bent shoots emerged near the cutting surface. This is likely the main reason for the high amount of bends. If wind break would be the main factor for stem bending, one could assume that tree clusters of the same height would be similarly affected. However, this was not detected in this study.

At HR and HS only 20 % and 33 % respectively of the stems were straight with no visible stem damage. The stem quality of minority tree species was even worse when compared to results from undisturbed stands. Here 50 % to 70 % straight and 80 % to 90 % undamaged stems were found (WEYERHÄUSER, 1998), it is clear that frequent fires and human activities led to the poor stem quality in the investigated stands.

3.6.3 Conclusions

Degraded DDF in Thailand have many young trees, a low stand volume and few trees of larger dimensions. Based on stump surveys, basal area utilisation and increment were balanced. The stocking volume and stem quality is not sufficient for quality timber production. Species composition was influenced by selective logging, fire and site conditions. Taken together, anthropogenic, fire and site parameters led to the present state of the degraded DDF. Nevertheless, the stand conditions provide several options to transform these stands into sustainable semi-natural production forests.

4 SILVICULTURAL IMPROVEMENT TREATMENTS

4.1 INTRODUCTION

In the two previous chapters, site parameters of degraded DDF were investigated and the stands chosen for the silvicultural improvement treatments were described. Here, proposals for improvement treatments are provided to transform degraded DDF into semi-natural production forests. Improvement intervention concepts were developed based, on the two experimental stands and production objectives.

As stand improvement treatments have never before been applied in degraded DDF temperate forests improvement treatment concepts were adapted to this forest type.

4.2 RESEARCH OUTLINE

Following a literature review of stand improvement concepts in tropical deciduous forests, different treatment variants were proposed. The implementation of these treatments at the experimental treatment stands HR and HS were described and analysed. However, at HR treatment interventions had to be delayed due to administrative obstacles. The Royal Forest Department will instigate these treatments at the end of the year 2000. Therefore, scenario results were provided instead.

Intervention treatments were conducted at HS previously. Here an initial assessment of the interventions in terms of their ecological, technical and economic outcome was undertaken. The economic outcome was based on the calculations from all the treatment variants, while timber extraction quantities and other parameters were described separately for each treatment variant.

4.3 REVIEW

4.3.1 State of management systems

To date, sustainable silvicultural practices have not been implemented in Thailand (WEYERHÄUSER, 1998). As a consequence most forests are degraded and increasing timber demand results in ongoing forest destruction. Thus there is a keen impetus to improve degraded forests and transform them into sustainable semi-natural managed forests.

The only applied management system was developed for teak forests (cf. Introduction). However, it was poorly implemented and controlled, which has resulted in the disappearance of teak forests today.

The management of DDF in Thailand in the past was less controlled than that of the teak forests (LÖTSCH, 1958). As a consequence, these forests degraded more rapidly. The only treatment concept proposed for the management of DDF was mentioned by BOONYOBHAS (1961). Stands should consist of 60-90 evenly distributed final crop trees per hectare, while in the lower story coppice shoots had to be cut in 20 year intervals. These treatments were forest type specific, however they were never implemented.

Internationally there is a lack of treatment concepts for tropical deciduous forests (SHEPHERD et al., 1993), compared to evergreen or semi-evergreen tropical forests, where several studies were conducted (WEIDELT, 1986; SUTISNA, 1990; SILVA et al., 1995; GRULKE, 1998). In deciduous tropical forests, vegetation and increment dynamics were investigated and different treatment concepts proposed (HAMPEL, 1997), but scant effort has been directed into research and development of silvicultural management systems (MAYDELL, 1996). The need for silvicultural systems in tropical deciduous forests is under debate (LAMPRECHT, 1990) as the simple structures and comparative paucity of species makes it possible to adopt silvicultural concepts, well-established in temperate regions. The aim of this research was to apply these in tropical deciduous forests under different climate, forest status and production goal parameters.

4.3.2 Management objectives for semi-natural production forests

Anticipated production objectives for semi-natural forest management were taken as follows:

- **Product preferences** - high-quality sawing timber, combined with a sustainable flow of fuel-wood and NTFP, like medicinal plants, herbs, wild fruits, bamboo, insects and honey for the local market. These products can be produced either separately under different management regimes or in a system with different production cycles spatially and temporarily linked with each other. The production of NTFP will not be separated from timber production.
- **Multi-functionality** - the forest serves as a multi-functional platform for production, protection and conservation purposes. To ensure protection functions such as soil erosion protection, a continuous forest cover is a prerequisite.
- **Subsistence dimension** - where subsistence forestry prevails, a reliable sustainable product flow has to be ensured. To provide forest subsistence functions permanently, a continuous forest cover is also necessary.
- **Economic task** - investment risks and profit expectations must be balanced. When the forest productivity is low, like in DDF, the investments and risks must be correspondingly low. For instance forestation, which is accompanied by a high fire risk in that region should not be approached.

4.3.3 Silvicultural pathways towards semi-natural forest management

Based on site and stand conditions as well as on the management objectives, stand transformation towards semi-natural production forests will be applied. In some cases natural regeneration may need extra assistance, for example in the form of enrichment plantings (LAMPRECHT, 1990), however these treatments were not required at the study stands.

Stands can be transformed into mono-cyclic or poly-cyclic stands, as remaining stocks and regeneration were sufficient.

- **Mono-cyclic stands** may also be called one cohort stands. A cohort is defined as a group of trees of comparable age and size (OLIVER & LARSON, 1996). Sometimes the concept also applies to species compositions. Vertical and horizontal structures are mostly simple. Regeneration processes usually start after large scale disturbances. In a mono-cyclic stand the entire marketable reserves are harvested in a single operation or within a limited felling period (LAMPRECHT, 1990).

– **Poly-cyclic stands** consist of two or more independent cohorts that differ in species composition, spatial and temporal pattern. Poly-cyclic stands have a permanent forest cover. Regeneration generally occurs in gaps. Though harvest interventions are usually small-scale (single trees, groups), highly skilled personnel are required for successful management.

4.3.4 Improvement treatments by future tree selection

Improvement treatments of degraded DDF on the basis of selecting **F**uture **trees** (F-trees) and removing their competitors appears to be the most promising rehabilitation strategy. The term improvement covers all domestication operations in growing stands which are intended to improve their future yields (LAMPRECHT, 1990). This so-called positive selection will usually lead to monocyclic stands if the selected F-trees are uniform in respect to dimension. Poly-cyclic stands occur in situations where the initial F-tree stratum is heterogeneous with diameter distribution (plenter-like diameter distribution) or where a small amount of F-trees were selected deliberately. This will lead to a coppice-with-standard situation, that is a canopy storey aimed at quality timber and a lower coppice aimed at fuel-wood production.

All other applied silvicultural approaches represent pre-treatments that will ultimately lead to the selection of F-trees later on. A typical example will be negative and group selection approaches. In the absence of sufficient F-trees the refinement of inferior stock serves to encourage the remaining stock and regeneration throughout the groups. Subsequently such pre-selection techniques will be followed by positive selection. The major F-tree selection principles are summarised in Tab. 4.1.

Tab. 4.1: Major principles for F-tree selection - ranked according to importance.

Criteria	Description
Quality	Dominant trees will be selected if they are straight, unforked and free of defects affecting tree vitality and growth. Fine branches and long branchless stem sections are valued F-tree characteristics.
Species composition	Species have to be classified and evaluated according to production goals (high value timber, fuel-wood, NTFP). F-tree selection should ensure that F-tree species composition reflects the envisaged production goal.
Protection of minorities	Rare species should be protected in any case to ensure that tree diversity does not decrease during silvicultural treatments, regardless of the quality of individuals.
Distribution	Potential F-trees should be evenly distributed. However, in many natural stands trees occur in groups. It might therefore be necessary to select small groups of F-trees and treat them as such.

4.3.5 Improvement treatment approach

Technically, improvement treatment interventions can be divided in two phases:

– In the height growth and branch clearing phase, F-trees are selected and consequently spaced from competing neighbours. Moderate tree competition is favourable in order to encourage self-pruning and fine branched stems. Branch pruning of F-trees in subsequent steps might be an option to increase the amount of knot free timber.

– The stand development phase, focusing on diameter increment, start once F-trees received dominance and the desired bole length is reached. Diameter growth and photosynthetically active leaf area are highly correlated. This gives individual trees sufficient space helps to develop the photosynthetically active leaf area and the crown

> size will increase correspondingly. As a result of spacing interventions, high diameter growth rates can be realised. The stand increment will be concentrated on the F-trees. In silvicultural literature this kind of improvement treatment in stands where tree DBH are 7 cm already, is conventionally called selective thinning (BURSCHEL & HUSS, 1997).

The underlying assumption of all positive selection treatments is that these selected trees benefit from liberation treatments reducing the competition from neighbours for light above ground and probably for nutrients and water below ground. In temperate forests competition for light is significant, while the competition for nutrients and water is only evident in some cases. In these forests crown competition reduction is the main objective. Additionally below ground competition is hard to measure, resulting in few studies on this topic.

4.3.6 Proposed intervention intensity and interval

Treatment intervention procedures should be carried out with moderate intensity and repeated after reasonable time intervals, depending on stand dynamics. In the context of the investigated community-types, more information on stand response to interventions is necessary to determine specific treatment intervals. Available crown space of F-trees may serve as an indicator of spacing demand.

Intervention intervals will range from 5 to 30 years. The treatment intervals for coppice systems will be relatively short, while for F-tree selection the time period is not necessarily the determining variable for an intervention. In many cases a defined period serves only operational purposes.

Besides silvicultural arguments, cost benefit analysis of the intervention practices needs to be considered. As a general rule, if the intervention interval is short, the timber outcome per unit will be low and management expenses accordingly high.

In a community forest context, flexible intervention intervals might best serve the timber demand.

4.3.7 Economic appraisal of sustainable timber production

Sustainable timber production requires economic incentives. In Thailand, the opinion prevails that timber management in DDF would yield no revenue. Thus, little attention was paid to management of DDF for economic timber production. In this study, monetary revenues and costs of improvement treatments will be analysed and discussed under different economic perspectives.

Inevitably, the economic feasibility depends on the revenue and the cost. The revenue derives from the extracted timber products and prices, while labour costs dominate the costs. This includes opportunity costs, which depend on the local socio-economic situation. In poor rural areas, forest work may be cheap and offset by forest products. Alternatively, if people earn higher wages in a booming industrial economy, opportunity costs will be much higher. Under these conditions only high timber revenues would support sustainable forest production.

4.4 MATERIALS AND METHODS

4.4.1 Determination of future tree figures

Little is known about the tree species specific relationship of crown development and stem diameter expansion in DDF. Realistic F-tree numbers depend on growth dynamics and product objectives: final crop diameter; bole length and production time span. F-tree numbers may be estimated based on reference stands.

The unmanaged and protected forest at MN used for site index studies (see Chapter 2) was considered as a suitable reference stand because the desired stem diameters at a given crown size had been reached. Though their age remains unknown it is possible to determine a realistic number of F-trees to cover the space on maturity.

Twenty four *Dipterocarpus obtusifolius* trees of this reference stand served to estimate realistic F-tree figures. Trees of final crop dimension, set at 40 cm DBH, had a mean height of 22 m. The mean branch-free stem length was 12 m. The mean tree height to DBH ratio was 0.5.

From all trees, crown radii measurements (following the main compass bearings) were taken to calculate the horizontal crown projection area. The relationship between DBH and crown projection area at the MN reference forest is displayed in Fig 4.1. The resulting linear function was f = 2.1 DBH - 27.6 and the regression coefficient $R^2 = 0.8$.

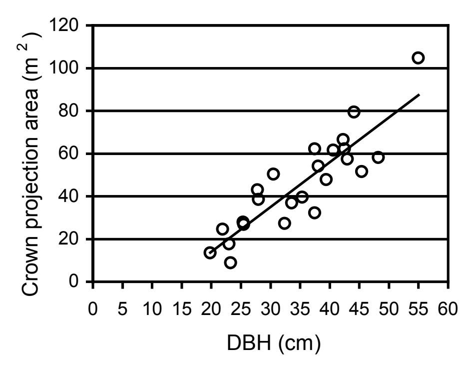

Fig. 4.1: Crown projection area of *Dipterocarpus obtusifolius* trees, plotted over DBH at the MN forest.

The required crown projection area was based on the desired DBH. Hereby the assumption was made that a fully stocked stand covers approximately 80 % of the forest surface. Thus, 45 m² growing space for each tree of the final crop was calculated and at final crop size, 180 F-trees ha^{-1} would be left.

It should be noted that these figures were calculated for mono-cyclic stands. To estimate F-tree numbers for poly-cyclic, plenter-like forests, F-tree figures should be approximately twice as high. In the research stands, the DBH of the F-trees was relatively homogenous, therefore a poly-cyclic, plenter-like forest was not an option.

4.4.2 Experimental designs

4.4.2.1 Experimental treatments

Based on information on stand conditions (Chapter 3), production objectives (Chapter 4.3.2) and estimated F-tree figures, two different treatments were defined for HR and HS. Two were applied on both stands, one extra treatment was tested at HR and two extra at HS. Each treatment was replicated three times and three control plots were set up on either stand (Chapter 2.4.1.1).

In Tab. 4.1, the treatment variants are explained. The objectives and treatment procedures are described. Furthermore, a treatment hypothesis was devised in order to test the outcome of the experiments at a later stage.

Tab. 4.1: Overview of the experimental treatments.

Treatment variant	Procedure	Objective	Hypothesis
F-tree selection, moderate numbers Tested at: HR and HS	Selection of 140 F-trees ha^{-1} at HR and 150 F-trees ha^{-1} at HS (see Chapter 4.3.5).	To study the relationship between stand density and diameter increment.	Spacing of F-trees improves their increment.
F-tree selection, low numbers Tested at: HS	Selection of 100 F-trees ha^{-1} (see Chapter 4.3.5). Pruning necessary.	To reach the timber production goal as early as possible.	DBH increment is higher than in the moderate F-tree selection approach.
Coppice with standard production Tested at: HR	Selection of 80 F-trees ha^{-1} (see Chapter 4.3.5). Pruning necessary. Strips of 10 m parallel to the slope are clear-cut, leading to coppice shoots of 7 to 10 cm DBH.	To produce a steady amount of fuel-wood and valuable timber in the long run.	Short-term benefits increase acceptance of controlled forest management.
Negative selection Tested at: HR and HS	Inferior stock is refined in several steps.	To increase stand quality and favour growth of desirable trees.	Spacing improves growth.
Group selection Tested at: HS	Canopy trees above promising regeneration groups are refined.	To encourage growth of natural regeneration clusters, if stand stem quality is not sufficient.	Spacing improves regeneration.

4.4.2.2 Treatment plot allocation

Individual plots were stratified and then randomly allocated to treatment variants within strata. The allocation of treatments aimed to homogenise the stand variability within the treatment replications for basal area and adult tree density. The values for HR and HS are plotted in Fig. 4.1.

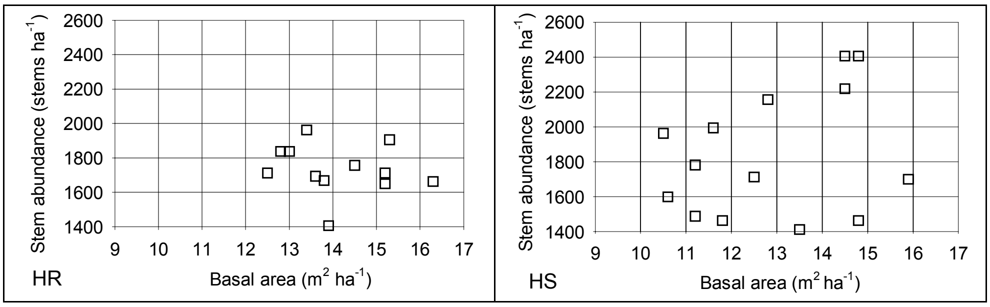

Fig. 4.1: Plot-specific basal area and tree abundance. Plot size 1600 m², trees ≥ 5 cm DBH.

Based on this information, plots and treatments were matched. For the two F-tree selection treatments, six plots with high basal area and stem numbers (upper-right of the two diagrams) were selected. Plots with low basal area and stem numbers were used for the negative and group selection variants. Control plots were set up according to the gradient of basal area and adult tree density. Thereafter the spatially stratified treatment and control plots were selected randomly.

4.4.2.3 Interventions

Interventions for the different treatment variants at HS are shown in Fig. 4.1. One intervention plot for each treatment variant is presented.

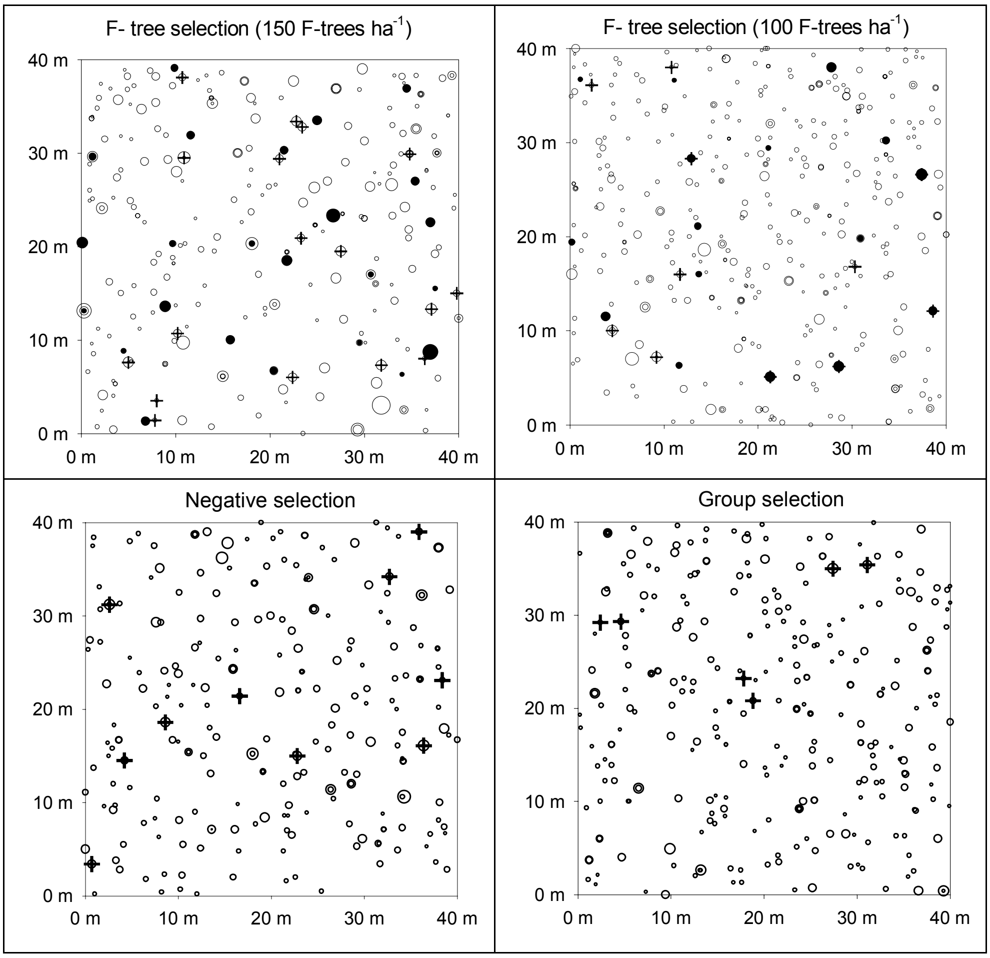

Fig. 4.1: Interventions for treatment variants at HS.

Depending on the variant, extracted trees (cross hair), F-trees (black circles) and matrix trees (plain bubbles) are presented. Circles are proportional to DBH.

The two **F-tree selection** intervention plots show that dominant trees of greater dimension were the preferred choice as F-trees. A uniform distribution of F-trees was envisaged. However, in some cases two trees close to each other were selected as F-trees and spaced accordingly, if necessary. Twin trees occurred often as a result of vegetative regeneration. In these cases, the tree next to the F-tree was removed (see Fig. 4.1. upper right). However, stem rot may present a problem for these F-trees.

The **negative selection** plot demonstrates that more trees as in the group treatment selection plot were refined. The number of extracted trees did not directly represent the total amount of malformed trees. Due to the high amount of malformed trees these have to be refined in two steps.

The **group selection** plot shows three areas where regeneration groups were spaced. In each case, the removal of two trees was sufficient to liberate the regeneration groups.

4.4.3 Treatment procedures

The improvement treatments at HS were conducted in February 1999 with the help of trained staff of the Silvicultural Research Station. The treatment design was agreed upon by the local administration and additionally at HR by the village committee. Interventions were conducted in a stepped approach displayed in Tab. 4.1.

Tab. 4.1: Improvement treatment procedures.

1.	Timber harvesting	Directional tree felling, based on two-man hand saws.
2.	Extracted timber bucking and quality assortment, according to quality grades	After felling, timber was measured and bucked to a top end diameter of 5 cm (over bark). Tree sections larger than 2 m were assorted according to quality grades.
3.	Forest fire prevention	Accumulated debris induces a high fire risk. As fuel-wood processing was impossible, debris were distributed evenly over the area. Harvesting was performed at the onset of the rainy season, to aid decomposition of flammable debris until the next fire season.
4.	Timber yarding	Manual timber yarding in 2 or 4 m stem sections.

4.4.4 Assessment of harvesting damage to remaining trees

Damage to the remaining trees during harvesting was recorded as follows (see Tab. 4.1).

Tab. 4.1: Harvesting induced tree damage types.

Damage type	Description
Crown damage	> than 50 % of the tree crown is damaged
Stem damage	Stem break during harvesting operation or bark damage in a way that the tree has to be down-graded to fuel-wood quality
Sapling damage	Stem break or severe damage of the bark

4.4.5 Timber assortment

Timber assortment was based on three timber quality grades (see Tab. 4.1).

Tab. 4.1: Timber quality grades.

Timber quality grade	Description
Saw-wood	High quality timber, free of external or internal damage, rot or malformations. Minimum dimension: 4 m bole length and a middle diameter ≥ 9 cm.
Low quality construction wood	Medium quality timber, with small damage, rot or malformations (for minimum dimensions see above).
Fuel-wood	Timber quality is lower than grade B

4.4.6 Economic analyses of the improvement interventions

4.4.6.1 Timber prices

A survey of the timber market in northern Thailand and the available literature was conducted, attached to this study (BECKER, 1999). The round-wood price survey at three major sawmills in northern Thailand was undertaken for teak and certain DDF hardwoods such as *Shorea obtusa*, *Shorea siamensis*, *Dipterocarpus obtusifolius*, *Dipterocarpus tuberculatus* and *Gluta usitata*. The round-wood prices for DDF hardwood were 70 % of the teak value. Small sawing wood prices were known, based on sales of 10,000 m^3 teak wood (see Tab. 4.1) processed by profile chip sawing sold in 1998 by the Forest Industry Organisation (SANGUL, 1999). The price for small dimensional sawing DDF hardwood was calculated from the relationship between round-wood teak and DDF hardwood and the price for small sawing teak.

Tab. 4.1: Wood prices of teak and DDF hardwoods in northern Thailand.

Product	Diameter and bole-length specifications	Teak US$/m^3	DDF hardwood species US$/m^3
Saw-wood	$d_{0.5}$: 9.0-13.0 cm; min. length 4 m	60	42.0
Low quality construction wood	$d_{0.5}$: ≥ 9 cm; min. length 2 m		20.0

Fuel-wood prices without delivery are summarised in Tab. 4.2.

Product	Price US$/m^3
Fuel wood	4

Tab. 4.2: Fuel-wood prices in northern Thailand.

4.4.6.2 Variable cost statement and work study calculation

The cost statement was based on variable costs for forest technicians and labour. Positive marking, negative selection and registration of extracted trees by forest technicians were included as variable costs. All the other forest technician duties were classified as fixed costs. Labour costs were calculated for two man handsaw harvesting with manual yarding. The use of chainsaws would improve labour productivity, however their use is prohibited in Thailand.

Work studies were conducted to investigate labour demand. The time in which a trained and motivated person of average ability would be expected to complete a specified job in specified circumstances (PRICE, 1989) was calculated. On top of the direct time taken to complete the single work cycle, an overhead time must be added for maintenance of working tools, together with a percentage relaxation allowance which varies with the job. Thus the standard time is: (direct time + overhead time) x (1+ relaxation %).

The daily productive working time was estimated at 7 hours. The time demand of the different harvesting activities - felling, limbing, bucking and yarding - depends on tree dimension and road distance. The calculation was based on a mean tree of 12.5 cm DBH and a mean distance of 45 m to the nearest road.

The daily allowance for forest technicians and labourer in Thailand was as follows:

- Forest technicians received a daily allowance of US$ 15.

– Labour costs were calculated as US$ 6 per day (paid by the Royal Forest Department in Chiang Mai for uneducated labour).

4.4.6.3 Gross margin calculation

A gross margin calculation, balancing variable costs and revenues of the stand improvement interventions was applied. Fixed or partly fixed costs of the forest enterprise were not considered as information on these costs (forest administration, road infrastructure, depreciation and investments) were not available. The calculated result was the gross margin.

Revenue (anticipated product retail price)
-variable costs
= Gross margin
- fixed costs
= Net revenue

4.5 RESULTS

4.5.1 Assessment of different semi-natural silvicultural interventions

4.5.2 Extracted timber

The extraction intensity at HS was considerably lower than the proposed extraction intensity at HR (Tab. 4.1). Differences reflect the lower site productivity at HS.

Parameter	HR %	HS %
Extracted trees	14.4	3.6
Basal area reduction	17.7	13.4
Extracted timber volume	28.9	8.5
Processable timber volume	n.a.	6.1

Tab. 4.1: Timber extraction intensity across all experiments. Proposed figures for HR, real figures for HS.

At HS, on average 65 trees ha^{-1}, or nearly 4 m^3 timber ha^{-1} was extracted. In Tab. 4.2, the results of the treatment interventions are presented for each treatment variant. The highest intervention intensity occurred at the 150 F-tree selection. With an increased number of F-trees, more competitors had to be removed to liberate the F-trees. With increasing F-tree numbers, smaller and less dominant trees had to be selected as F-trees and accordingly, more competitors had to be removed. The lowest intervention intensity was necessary during group selection, however timber volume per extracted tree was relatively high.

Processable timber was defined as timber with a minimum top diameter ≥ 5 cm. Due to this low value, extracted and processable timber volume did not differ dramatically, except for the group selection where bole length of the extracted trees was extraordinarily short.

Tab. 4.2: Timber extracted from the different experimental plots at HS.

Parameter	**F-tree selection** **150 trees ha^{-1}**	**F-tree selection** **100 trees ha^{-1}**	**Negative selection**	**Group selection**
Extracted stems ha^{-1}	94	60	71	35
Mean extracted trees/F-tree	0.9	0.6		
Extracted timber m^3 ha^{-1}	5	4	4	3
Processable timber m^3 ha^{-1}	4	3	4	1

Tree volume (solid volume over bark) was calculated with the Huber formula (KRAMER & AKÇA, 1987): $V = g_m L$. (g as the basal area in the middle of a stem; L as the stem-length)

In Tab. 4.3, figures for the proposed timber extraction at HR are presented. On average, 259 trees ha^{-1} and 12.2 m^3 ha^{-1} of timber were to be extracted. Compared to HS, more stems and a higher timber volume would have been extracted. The treatment intensity measured in terms of stem number extraction would have been four times higher, while the volume extraction would have been only three times higher at HR.

Tab. 4.3: Proposed timber extraction from the different experimental variants at HR.

Parameter	**F-tree selection** **140 trees ha^{-1}**	**Coppice with Standards production**	**Negative selection**
Extracted trees stems ha^{-1}	100	417	260
Mean extracted tree per F-tree	0.7	3.0	
Extracted timber m^3 ha^{-1}	11	12	14

Tree volume (solid volume over bark) was calculated with the in Thailand applied volume function $V=g_{1.3}h\ f$ ($g_{1.3}$ as the basal area at 1.3 m; h as the tree height and f as the false form quotient. An artificial form factor of 0.4 is used in northern Thailand for DDF stands of a mean DBH between 5-15 cm (PUNCHAI, 1999).

At HR, the highest extraction intensity for the coppice with standards production was proposed, because in each plot a strip of 10 m by 40 m, with only previously marked F-trees, were allowed to remain. Cutting of the coppice shoots would follow at an interval dependent upon the growth of these coppice shoots. The highest extracted stem volume is expected for the negative selection treatment.

4.5.3 Wood quality

From the extracted timber, 73 % can be processed. As displayed in Tab. 4.1, 41 % of the processable timber can be graded as saw-wood and would be planked if the profile chip sawing technology was available. 52 %, of the processed timber was graded to low quality construction wood and 7 % was only suitable as fuel-wood.

Wood quality	**Processable timber** m^3 ha^{-1}
Saw-wood	1.7(41 %)
Low quality construction wood	2.2 (52 %)
Fuel-wood	0.3 (7 %)
Total	**4.2 (100 %)**

Tab. 4.1: Timber quality at HS.

4.5.4 Stand damage during silvicultural interventions

Stand damage during treatment interventions was unavoidable. In particular damage to trees of poly-axes growth, when felling large individuals. However, improved felling techniques and strictly defined felling directions could reduce stand damage.

Across all treatment variants, approximately 0.4 % of the trees were damaged (Tab. 4.1). Crown damage (0.1 %) was less frequent compared to stem damage (0.3 %). Damage to saplings was also low, just 0.1 % of the saplings suffered from treatment interventions.

Tab. 4.1: Damage occurring during treatment interventions at HS.

Tree damage stratum	Damaged trees in relation to extracted trees %	Damaged trees in relation to remaining trees %
Sapling damage	3.2	0.1
Crown damage	3.2	0.1
Stem damage	7.4	0.3
Total adult tree damage	**10.6**	**0.4**

As expected, the damage caused was proportional to the intervention intensity. Minority species were often damaged during operations. In the case of *Cananga latifolia* and *Buchanania lanzan* this can be attributed to the tree architecture.

4.5.5 Economic analysis of the silvicultural treatments

The work studies recorded a time demand of approximately half an hour to extract one tree with a mean DBH of 12.5 cm (Tab. 4.1), involving a forest technician and fire prevention costs. Felling and timber yarding consume the majority of this time. The forest technician spent 2 hours ha^{-1} to conduct the positive and negative tree selection, including timber registration. Approximately 30 % of the total time taken was spent on maintenance of tools or on the relaxation allowance, the actual breakdown between these two elements varied with each task.

Tab. 4.1: Time demand of intervention treatments at HS.

Activity	Total time demand minutes/person/tree	Direct time %	Overhead time %
Forest technician duties	2	80	20
Timber felling	13	70	30
Timber limbing and bucking	6	70	30
Timber yarding	8	60	40
Forest fire prevention	2	70	30
Total	**31**	**70**	**30**

Based on the work studies and cost calculations, the time demand and associated costs to extract one cubic meter of timber is presented in Tab. 4.2. Harvesting of one cubic meter including associated activities took 1.4 man days and caused costs of US$ 18.

Variable costs	Time demand days/person/m³	Costs US$/m³
Timber felling	0.5	5.9
Timber limbing and buck	0.2	2.7
Timber yarding	0.3	3.6
Fire prevention measurements	0.1	0.9
Subtotal labour costs	**1.1**	**13.1**
Tree marking	0.1	1.1
Timber registration	0.3	3.8
Subtotal forestry technician costs	**0.3**	**4.9**
TOTAL	**1.4**	**18.0**

Tab. 4.2: Variable costs of stand improvement treatments at HS.

The economic analysis sheet of the stand improvement intervention is presented in Tab. 4.3. If only fuel-wood can be sold, no positive gross margin will be achieved. Revenues for saw-wood and construction wood covers the variable costs. However, a positive gross margin can only be achieved if fuel-wood is sold in conjunction with construction timber.

Tab. 4.3: Economic analysis of variable costs and benefits at HS.

Product	Timber prize US$/m³	Variable costs US$/m³	Gross margin US$/m³
Saw-wood	42	18	24
Low quality construction wood	20	18	2
Fuel-wood	4	18	-14

The gross margin calculation for HS is presented in Tab. 4.4. The extracted timber would gain revenues of US$ 130, however the variable costs were US$ 140. Therefore the gross margin at HS would be US$ -10. A positive gross margin of US$ 45 for the 1.92 ha treatment area would be achieved if saw- and construction wood would be extracted only and if outsourcing of fuel-wood extraction would cover the costs for the forestry technician.

Tab. 4.4: Economic analysis of silvicultural treatment operations at HS.

Product	Extracted timber m³/1.92	Revenues US$	Variable costs US$	Gross margin US$
Saw-wood	1.7 (22)	71	31	41
Low quality construction wood	2.2 (29)	45	40	4
Fuel-wood	3.8 (49)	14	69	-56
Total	**7.7 (100)**	**130**	**140**	**-10**

4.6 DISCUSSION

4.6.1 Methodological aspects

It was difficult to apply comparable treatment intensities within the replications of this study, due to the heterogeneous nature of the selected F-tree collective. The amount of competitors removed and timber quantities extracted differed markedly between treatment replications and the two stands investigated. Fixed sized extraction quantities, such as 2 competitors per F-tree or 100 malformed trees per hectare, would homogenise treatment intensities, but were not feasible due to stand heterogeneity and management targets. For improved data quality, subsequent research on the subject would require larger sample plots.

This would also enhance the representativeness of the wood quality timber assortment. The overall timber yield at HS (about 8 m^3 1.92 ha^{-1}) was too small to analyse the timber outcome for each variant separately.

At HR the experimental treatment interventions were not possible. Until the actual treatments can be applied, direct comparisons between the surrogate data of HR and the actual treatment data of HS must be treated with caution.

For the silvicultural treatment design, there is a lack of information on the dynamics of crown development of DDF species. To determine an optimal number of F-trees, an approximation of crown space demand at target diameter was derived from an unmanaged forest nearby. With the help of a linear DBH to crown projection area regression function, the F-tree densities at specific DBH were calculated. A linear regression was achieved for *Shorea obtusa* and *Shorea siamensis* in west Thailand (WEYERHÄUSER, 1998) and a similar function was determined for *Dipterocarpus obtusifolius*.

The selection of competitors was based on crown space competition. Silviculturally and practically this is the most adaptable and flexible approach. However, from an ecological perspective, this approach might not fully consider possible competition for water and nutrients.

The economic analysis of the improvement treatment interventions could be performed in two ways. Economic figures for each separate silvicultural variant are required for a detailed discussion about the most promising concept. Nevertheless, in view of the political difficulties to conduct these experiments in Thailand, this research provides unique and valuable preliminary information on the economic potential of degraded DDF.

A second constrain of the approach was that data could only be obtained for timber harvesting. The subsequent stages for achieving timber prices, quality and quantity of processed sawing timber or other processing needs requires further evaluation.

The information on timber prices should be taken with caution due to low market transparency and a strong black market for timber.

4.6.2 Silvicultural treatment aspects

A series of silvicultural improvement treatments had been set up and the first treatment intervention was assessed. The experiments proved that to increase forest quality and to favour trees of desirable species and stem form, low intensity interventions are sufficient, provided they begin at an early stage.

The applied F-tree selection received most attention by the local people. The selection of trees with favourable attributes and protection for the benefit of future generations has been undertaken by Buddhist monks in Thailand for centuries. However the selection criteria are different.

To combine short term benefits with long term quality timber production, a treatment scenario was analysed where coppice shoots were harvested on a short rotation basis, while some F-trees will be managed on a longer rotation to provide high quality saw-wood. As expected this scenario yielded the highest stem extraction rate per ha.

Also, negative and group selection were applied to improve the overall stand quality. However it is proposed that these treatments will be followed by F-tree selection at a later stage.

Group selection, as applied at HS, is the least extensive intervention (mean 35 stems ha^{-1}). Only very few regeneration groups could be identified worth liberating. This was influenced by the two past extraordinary dry seasons (1997 and 1998), suppressing or even preventing regeneration.

Negative selection criteria were difficult to define due to the heterogeneous nature of the stand. The intervention criteria to remove inferior stock (amount of malformed trees and dominant species) had to be defined in relative terms, because intervention intensity was restricted in order to retain most of the forest characteristics. This resulted in a great variability between the treatment replications.

At HS, across all treatments nearly 4 m^3 ha^{-1} was extracted while it was planned to extract approximately 12 m^3 ha^{-1} at HR. This reflects the higher yield at HR and considered the expected growth dynamic.

During the selection, attention was given to maintain species diversity. The negative selection treatment scenario at HR will increase species evenness. The dominant species *Dipterocarpus tuberculatus* was selected primarily to increase the proportion of other, more valuable species. *Dipterocarpus tuberculatus* is known for its poor stem form and low timber value. Its dominance is not natural but rather the result of deliberate omission during harvesting.

The recorded stand damage during harvesting operations to the remaining stand at HS has to be treated with caution. Due to the overall low dimensional trees, the small size of the experimental plots and the better than usual performance of the forest workers, the harvesting induced damage to the remaining crop was low. Less than one percent of the remaining trees were damaged. This amount of damage can be considered as exceptionally low. During other experimental treatment interventions, conducted in degraded forests in Paraguay (GRULKE, 1998) and Chile (POKORNY, 1995) at higher stocked stands, 16 % and 35 % respectively of the selected F-trees were damaged by the treatment interventions.

At first sight, a 5 cm lower diameter limit for utilisable timber might appear small. However, considering the local timber scarcity and the market demand, the figure is justifiable. As a result, the difference between the total volume extracted and the volume of processable timber is low.

In summary, though growth rates are poor, the results proved that the forest quality can be improved with semi-natural silvicultural interventions. However long term assessments of similar experiments are necessary to draw final conclusions and to formulate a forest management practice guideline.

4.6.3 Economic analysis aspects

The following discussion of the economic results will focus on two aspects. First, the results of the gross margin calculations will be discussed, sensitive factors influencing the calculation will be noted. Secondly, one limitation of gross margin calculations is that they omit the social context of the people involved.

The advantage of the situation of DDF in Thailand is that regeneration is sufficient and the revenue from improvement treatments can at least partly cover the costs for these treatments. Forestation involving high investments and risks was not necessary. Even in the investigated young and degraded stand at HS the expected revenue of timber sales covered more than 90 % of the variable treatment costs. Fuel-wood utilisation resulted in a negative gross margin between US$ 14 and 15 per m^3.

This situation is in contradiction to the situation of exploited forests in East Paraguay (GRULKE, 1998). The forest stock there is much higher, but fewer local residents are interested in utilising fuel-wood and lower saw-wood prices (less than US$ 20 m^3) can be realised for greater dimensional timber. Under such conditions revenues of timber sales covered less than 80 % of the variable costs of the stand improvement interventions.

Fortunately it seems that the construction market in Thailand values the quality and dimensions of that produced at HR and HS (BECKER, 1999).

The availability of suitable machinery is a limitation for the extraction and processing of low dimensional saw-wood and construction timber. During the next decades the most extracted timber in Thailand will be harvested from relatively young plantations and degraded forests. Economically investments in sawing technology, like profile chip saws, will be crucial to gain positive revenues from small dimensional timber.

Fuel-wood production calculated with labour costs did not even cover the variable costs. However, if fuel-wood is further processed into charcoal, the cost revenue calculation may be different. This is because the price for charcoal is steadily increasing, not only resource-poor households prefer to cook with charcoal but it is also the traditional way to prepare many dishes.

Under supervision of experienced forest technicians, improvement treatments could be carried out by local people as well. Even with low stumpage fees, stand quality would increase and the forest authority would attain control over the so far uncontrolled cutting activities. If no local people willing to pay a minimum stumpage fee are at hand, who would have conducted the precisely described improvement treatments, then only the F-trees selection can be applied to keep costs as low as possible.

Revenues from timber sales have, thus far, been taken as the measurement of whether or not improvement treatments are economically feasible. Cost benefit analysis considering social values and multiple objectives might result in different economic outcomes (ENTERS, 1992). Many people in remote areas of Thailand have no opportunity costs, which means they have no income alternative. The benefits gained from fuel-wood processing, selling and NTFP utilisation are essential. Most of them cannot afford other sources of energy and rely on fuel-wood from the forest. They consume approximately between 100 and 3,000 kg (mean value 700 kg) per person per year (SAROBOL, 1994). The majority of the people in rural northern Thailand would be willing to join a planned forest management approach in order improve their source of income (SAROBOL, 1994). Given this situation, improvement treatments could be conducted by the local residents. A cost benefit analysis of improvement treatments under such conditions could yield alternative results for the feasibility of improvement treatments in Thailand.

4.6.4 Conclusions

To this end, even under the actual economic conditions where funds to rehabilitate degraded forests are restricted, stand improvement treatments are economically feasible. The obtained economic results justify silvicultural management. The application of the proposed treatment concepts need to be assessed on a long term basis. Once, high quality timber can be extracted, positive gross-margins can be achieved. Thus, since DDF is the most prominent forest type in Thailand, the Royal Forest Department should not continue to neglect its economic potential. It has proved that successful management of these resources can only be realised if local communities share the responsibility and the benefits with governmental agencies.

5 GENERAL DISCUSSION AND CONCLUSIONS

5.1 EVALUATION OF THE STUDY RESULTS

Optimal forest protection, through a total logging ban or controlled forest utilisation, is presently a topic of intense debate, not only in Thailand (FAO, 2000). However, even after the logging ban, forest exploitation has not stopped and deforestation rates remain high (Chapters 1 and 3). Therefore it seemed reasonable to look for other possibilities to protect the forest. Here, the approach to protect the forest by increasing its utilisation value was explored.

In this study, site and stand baseline parameters of degraded DDF were investigated and proposals provided to transform these forests into semi-natural production forests. The proposed treatments were applied and economically assessed. Based on these results, the potential to increase the utilisation value of degraded DDF will be discussed in this chapter and research needs will be outlined. In Fig 5.1 the dimensions to assess the potential of degraded DDF are displayed. In this context the potential of a forest is defined by the desired management objectives, the actual status of a forest and the available energy and resource inputs required to reach these objectives.

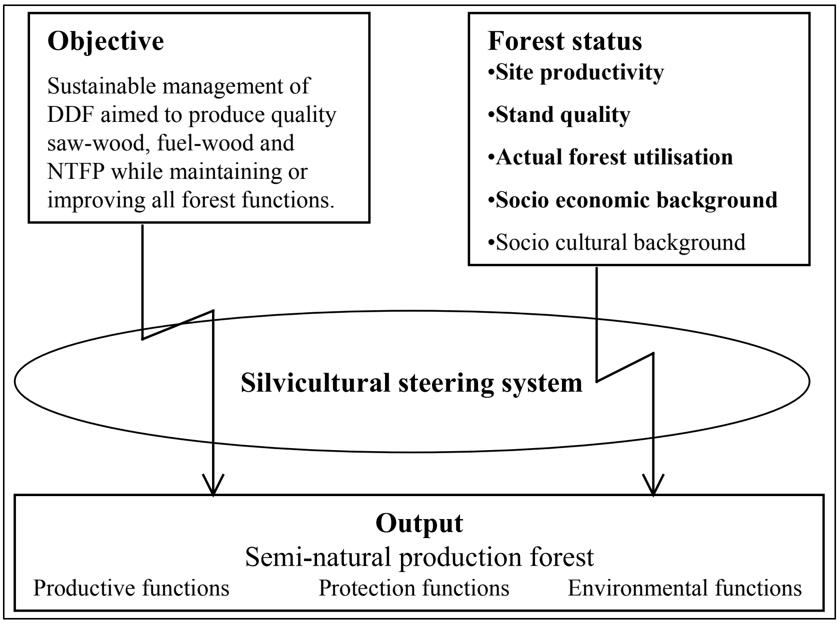

Fig. 5.1: Dimensions of DDF potential assessment.

The box on the left represents the management objectives, which were anticipated within the study. In the box on the right, the forest status is defined and the investigated aspects are depicted in bold letters. The energy necessary to reach the objective are symbolised by the two lighting symbols. Within the framework of economic efficiency, silviculture becomes the management tool to direct the forest stands.

5.1.1 Site potential

The study provided information on how to assess site quality and productivity in DDF stands. Different site assessment approaches were compared with each other and site index information was provided.

Vegetation analysis proved to be suitable to distinguish undergrowth tree and non tree species, typical for xeric DDF sites from characteristic species for more mesic site conditions. Site potential is lower for naturally nutrient-poor degraded DDF sites than for degraded DDF due to forest exploitation and fire. This is because, soil conditions were more favourable and can be expected to improve once forest exploitation and uncontrolled burning stops. However, the time demand for the latter site recovery is still unknown.

Soil studies provided direct information on site quality. Information on clay and phosphorus content can explain majority of the variability between sites. However, site productivity can not be predicted by a single parameter. The combination of the parameters determines the site productivity. For example, phosphorus seems to be a growth limiting factor, but its availability depends on the pH.

The estimated **site indices,** provide direct information on site productivity. These indices ranged from 6.9 to 14.2 m. This indicates, that DDF site productivity is not generally poor, confirming the vegetation analysis studies. On productive DDF sites, stand improvement treatments have the greatest potential for timber production.

5.1.2 Stand potential

A common feature of the investigated stands was the high stem abundance and the low stand volume. Accordingly the average stand DBH was only between 8.5 and 9 cm and few trees of greater dimensions remained. A considerable amount of stems were of poor quality.

However, due to the high stem abundance there is still a sufficient amount of trees with favourable stem attributes to transform these stands into semi-natural production forests. Seedling abundance was sufficient, but sapling abundance and quality was rather low.

These stand conditions would allow several silvicultural treatment options. Nevertheless vertically structured, plenter-like forests are difficult to achieve due to the relatively homogenous nature of the stands.

At the present state, forest structure serves only fuel-wood production purposes, because regeneration from sprouts is plentiful and vigorous. Stand age and stem quality do not play a major role. However, stand requirements are different if quality timber production is the aim. Clearly, stem quality parameters like stem damage and straightness of stems will become important. Additionally, stand age and standing volume indicate stand quality in so far as they influence the time span until the desired product can be harvested. In this respect, the actual quality timber production potential of the investigated stands was low. Furthermore, the production potential is restricted by the poor annual diameter growth dynamics (compare Chapter 3). However, as demonstrated above, the stands investigated represent not the upper site productivity range.

5.1.3 Economic feasibility of silvicultural improvement treatments

Stand improvement treatments are advisable for all degraded DDF stands where timber production is planned. In light of the limited experience and the scarcity of available economic resources, improvement treatments should start on a small scale, where the cost-benefit relation is most favourable. Thus, a degraded DDF stand should first be stratified according to prevailing site potential, stand status and the surrounding socio-economic situation.

When comparing cost and benefits the intervention treatment and harvesting conditions (see Chapter 4.6.3) will affect the costs most readily. The potential benefits depend on timber quality, quantity and the prevailing timber market (prices, distance to and number of customers and suppliers). Stand basal area, stem density and stem quality can be used to predict the economic outcome.

Since fuel-wood extraction calculated with labour costs did not even cover the variable costs (compare Chapter 4.4.6), the greater the amount of logs that reach saw-milling dimension, the lower the economic loss of the improvement treatments.

Benefits such as erosion control and an increase of biodiversity that result from improvement treatments are difficult to quantify economically: market prices for such benefits are not established. Similarly, benefits accruing to local residents from products and services as a results of an improved forest status (in the form of income from NTFP utilisation and fuel-wood) are also difficult to quantify. Since the goods are often not traded it is difficult to assess their monetary value.

For the case of the conducted improvement treatments, present gains from timber sales do not cover variable costs. However, if the proportion of high quality processable, saw-milling sized logs can be increased by improvement treatments, a future positive gross margin can be expected. In areas where fuel-wood scarcity prevails, residents might be interested in conducting improvement treatments in return for a sustainable flow of fuel-wood. An opportunity-cost investigation would need to be applied to find out under which conditions people would be willing to conduct the forest operations.

However, the prospect of future income from quality timber sales may not be a sufficient incentive for the local people to invest in forest improvement. Particularly, when private forest utilisation rights and structures do not exist. Secure access to future benefits and a bonus system for good forest management practices could be incentives to overcome such short term thinking.

This study did not further investigate the socio-economic context surrounding the forests. Other authors have pointed out the close correlation of forest status, the regional socio-economic situation and cultural background (LEUNGARAMSRI & RAJESH, 1992; SAROBOL, 1994; VICTOR et al., 1998; BRENNER et al., 1998).

5.2 PROSPECTS TO ESTABLISH SEMI-NATURAL PRODUCTION FORESTS

5.2.1 Possible gains

A requirement of planned management is that all parties involved accept the termination of uncontrolled harvesting and that subsequent treatments will be conducted in accordance to a defined management plan. Without improved land use planning and planned forest management approaches, the forest resources will continue to degrade or destroyed completely. The proposed approach would transform degraded DDF into semi-natural production forests by forest improvement treatments and controlled utilisation.

Environmentally sensitive forest areas urgently need conservation. However, in the light of the prevailing timber demand, the majority of DDF would have to fulfil both productive and protective functions. This is the main purpose of semi-natural silviculture. In contrast to ill-managed forest conservation, resulting in progressive forest degradation and final destruction, semi-natural silviculture provides timber and NTFP utilisation as well as environmental and protection functions of a stand.

Semi-natural forest management will increase the growing stock and in this way it can contribute towards carbon dioxide mitigation. Such mitigation effects are on the way to become an internationally tradable good. However, there is also a trend to only accept sequestered carbon dioxide that has accrued in a sustainable way without pre-empting local development. Semi-natural production forests, while fulfilling community-based forest objectives are well suited for this criteria.

The income from degraded DDF management depends on the environmental limitations to growth that prevail in such areas. Consequently, investments and production constraints and risks must be balanced. Semi-natural forest management involves relatively low costs and production risks, especially when compared to plantation approaches. Semi-natural forest management suits a wide range of management forms. It can be conducted by local communities as well as by government agencies. However, highly skilled personal are necessary, for both planning and executing the necessary interventions.

5.2.2 Implementation problems

(1) The first and main argument opposing any kind of legal forest utilisation is that once the prevailing total logging ban is lifted, it will be difficult to distinguish planned from unplanned forest management practices.

(2) Furthermore, due to the strict logging ban, there is no experience in the country on how to improve degraded forests and monitor sustainable forest management. The only forest technician training centre has been closed a few years ago. The logging ban has restricted the major function of the Royal Forest Department. In the present situation, functions of administration and law enforcement (logging ban) prevail, while forest management and research should be its main objective. This would also transform the relationship with the local people from opponents to partners. Forest officers should become forest managers.

(3) Improved forests might attract economic interests from outside and prevent local people from participating in the returns, while degraded forests can be exclusively used at the

disposal of local residents. Undoubtedly, rehabilitated, more productive and more valuable forests will attract more economic interests. To prevent exploitation from outside, equitable land use and ownership agreements have to be reached beforehand. If agreements are revoked, attempts to rehabilitate forests will fail, as demonstrated by an example from Laos. In 1993, the Government granted communities in southern Laos the full rights and responsibility to manage nearly 10,000 ha of forests for their own benefit. In return, local communities had to pay fixed royalties to the Government (MANIVONG & MURAILLE, 1998). The implementation of the sustainable forest management system, supported by development agencies, turned out to be a success story and yielded a steady source of income for the communities. Recognising the degree of potential benefits, the local forest department tried to revoke the agreements, leading to a collapse of this attempt.

(4) Forest utilisation by individuals will not be possible, once a planned management approach is implemented. For people relying on a subsistence economy, this will threaten their livelihood. Individual needs and economic activities should be combined into systematic management approaches. As an example, controlled logging would provide fuel-wood for local people and high quality timber in the future. The Royal Forest Department should act as a service provider. Together with the local residents and other government agencies, utilisation contracts need to be negotiated and management plans developed. The performance of the management plan should be evaluated by all parties involved.

(5) Thailand officially protects 70 % of the remaining forest area for conservation purposes, to revise these decisions and to approach sustainable forest utilisation might result in a loss of credibility, because a high proportion of conservation areas is appreciated from International Development Banks during credit assessments. However, there is a sharp discrepancy between legal status and actual protection success. The establishment of protected areas was a top down approach from the government agencies. As a consequence, the protective status is ignored and forest exploitation is continuing.

5.3 RESEARCH AND DEVELOPMENT NEEDS

In spite of concerns about forest utilisation, it can be expected that community based forest utilisation will be introduced. Optimal forest management rests on solid research results. Therefore silvicultural and related research is important. A nationwide network of forest monitoring and silvicultural experimental plots is required to investigate both natural forest dynamics and test silvicultural options. Hereby an important task will be to standardise sampling and analysis methods and ensure public data access. Important research targets will be outlined below.

Site-adapted forest management

The site information currently available is not sufficient for planning any forest resource management. Site productivity information is a prerequisite to set sustainable harvesting quantities. Thus direct site productivity measurements based on the site index approach outlined in Chapter 2 should be applied. Site survey methods should be tailored to local individual applications, but standardised methods are important to secure data comparison on a national level as well.

Improvement treatment concepts

Improvement treatments were conducted in relatively young stands, where the site productivity was relatively low. To study improvement treatments under different site conditions, they need to be applied in older stands and on higher productivity sites.

Silvicultural potential of indigenous species

During the study, some indigenous species like *Dalbergia fusca* and *Pterocarpus macrocarpus* showed favourable growth and these trees are also known for their valuable timber. Besides in depth information on growth rates, more information about their silvicultural attributes are necessary. Propagation techniques should be investigated and enrichment planting trials set up in areas where natural regeneration is not sufficient.

Growth response to spacing

There is no information on growth response to spacing and due to the relatively low growth dynamics, information from the established experiments may be not available for some time. Growth studies on solitary trees would provide information on maximum increment values. To explore the increment affects of spacing, different spacing regimens should be further investigated. Factors such as social position and development stage should be considered.

The below-ground competition for nutrients and water should be explored. Therefore, tree growth has to be studied under different ground vegetation situations to determine the extend of its impact on tree growth.

Long term effects of short term fire intervals

Clearly, short forest fire return intervals decrease the genetic variability of DDF species, because vegetative regeneration is favoured and seed dispersal, by mammals, is prevented due to decreasing wildlife populations. However, the consequences of different fire return intervals on regeneration composition, growth and seedling establishment remains unclear.

Economic benefits from planned forest utilisation

Depending on the applied treatment concepts, further investigations on economic benefits should be conducted along with future treatment interventions. A quantification of the income from NTFP and its changes in relation to different treatment interventions would be also important.

Benefits from planned forest utilisation also depend on the objectives of the diverse stakeholders. These can range from subsistence-based local residents, to people marketing products in vicinity to the forest, to regional product traders and finally to land title brokers. It is important to understand the behaviour of these stakeholders and to understand the prevailing conflicts and the impact on forest condition and forest area development.

Interdisciplinary forest research

Since the publication of "Thailand after the Logging Ban" (LEUNGARAMSRI & RAJESH, 1992), forestry is recognised as a socio-economic issue. The presented research findings, though initiated from a silvicultural perspective, are strongly linked to socio-economic processes. In the future it will be necessary to integrate information from different academic disciplines. Locally applied forest utilisation systems may serve as case studies. Although previously studied by social scientists, they should be studied by a combination of ecologists and foresters to devise socially acceptable and silviculturally sustainable management systems.

6 SUMMARY

Over 30 years, the forest cover in Thailand declined from 50 % in 1961 to 25 % in 1991. To stop forest exploitation and destruction, the Thai government declared a nationwide logging ban in 1989. Nevertheless, the annual deforestation rate between 1990 and 1995 was estimated at 2.6 %. This shows that total forest protection does not stop deforestation so long as timber and land demand prevails.

In the future, maybe 10 % of the forest area should be effectively protected for conservation purposes, another 10 % could be managed intensively as forest plantations. Of the remaining 80 % it might be impossible to segregate forest functions. These forests would serve both production and protection purposes.

Most of the forests in Thailand available for timber production are degraded and grow on marginal sites. To restore the full production potential of these forests, improvement treatments are necessary.

The aim of this study was to investigate:

- site quality and productivity;
- stand status and dynamics;
- improvement treatment possibilities to transform these forests into semi-natural production forests.

This study was conducted in northern Thailand and focussed on degraded Deciduous Dipterocarp-Oak Forest (DDF), one of the major forest types in Thailand. It is also found elsewhere in continental Southeast Asia where low competition from other land use has facilitated forest retention on marginal sites.

Characterisation of DDF site quality and productivity

Initially, site productivity was investigated to select DDF sites where future silvicultural improvement treatments can be expected to have optimal impact.

To distinguish different site conditions, soil and undergrowth vegetation were analysed. These indirect measures of site productivity were compared with results derived from site index studies on *Vitex limoniifolia*.

Soil analysis showed that 86 % of the site variability can be explained by the clay and phosphorus content. Cluster analysis based on these parameters was successfully applied to distinguish sites from each other.

Tree and non tree undergrowth vegetation analysis confirmed these site classification results. On the more marginal sites, canopy and undergrowth vegetation is dominated by typical DDF species, while on the other sites only the canopy trees correspond to DDF. The undergrowth species indicate more mesic vegetation types. On these sites the degraded DDF is probably a result of fire and selective cutting-induced regressive succession.

Site index studies, based on stem section analyses of *Vitex limoniifolia*, found site indices between 6.9 and 14.2 m at a reference age of 30 years.

Independently all three site assessment approaches recorded differences between the investigated DDF sites. However, due to their focus on different aspects, site classification results differ from each other.

Description of degraded DDF stand conditions and dynamics

To propose stand adapted improvement treatments, stand conditions and dynamics had to be analysed. Species richness was impoverished in the investigated degraded stands compared to less disturbed stands of the same forest type. Species composition was dominated by four *Dipterocarpaceae* species. Stem density (DBH ≥ 5 cm) was high (1,750-1,800 stems ha^{-1}). However, as expected, basal area (12-13.5 m^2 ha^{-1}) and stand volume (41-51 m^3) was comparatively low. The low sapling (DBH < 5 cm) quality and density (between 1,400 and 2,350 saplings ha^{-1}) are crucial for any stand improvement approach. In contrast seedlings were plentiful (11,500-18,000 seedlings ha^{-1}) and did not restrict stand improvement. Stands were characterised by a narrow DBH distribution, more than 90 % of the stems had a DBH between 5-15 cm, few trees of larger dimension with poor stem form occurred. Growth dynamic was poor, the median annual DBH increment of the dominant species was between 0.1 and 0.3 cm y^{-1}.

The ongoing uncontrolled forest utilisation with cutting rates of 29-80 trees $ha^{-1}y^{-1}$ led to selective cutting of more valuable tree species, especially in DBH ranges where DDF species start to set fruits. However, the basal area reduction due to uncontrolled illegal cutting and the basal area increment was approximately balanced in the investigated stands.

Development of stand improvement treatment concepts, application and assessment

The early development stage of the stands permitted testing of several silvicultural treatment concepts. The main concept applied was the future tree selection, where these trees were selected and their competitors successively removed. This concept was tested with different numbers per area.

Also, negative and group selection were applied to improve the overall stand quality. However, it is proposed that these treatments will be followed by future tree selection at a later stage. To combine short term benefits with long term quality timber production, a treatment scenario was analysed, where coppice shoots will be harvested on a short rotation basis, while some trees will be managed on a longer rotation cycle to provide high quality saw-wood. At one stand, nearly 4 m^3 timber ha^{-1} was extracted for all treatments, while it was planned to extract approximately 12 m^3 ha^{-1} at the other research stand.

The economic analysis across the treatment variants, resulted in a negative gross margin. However, when saw-wood and low quality construction wood is extracted at a greater proportion, a positive gross margin can be achieved.

Potential of DDF management

Considering the large amount of degraded DDF in Thailand, these resources hold a great potential for sustainable timber production. The present situation of uncontrolled forest utilisation and destruction can be only improved if controlled forest management practices are adopted instead. Hereby the transformation of degraded forests into semi-natural production forests as proposed and tested proved to be a promising approach

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10 APPENDIX

Appendix 1: General map of Chiang Mai vicinity (source: ICRAF, Chiang Mai). Research sites: HR: Huai Rai; HS: Huai Som; MN: Mae Naa Baa; PC: Pa Cha Lua.

Appendix 2: Aerial photographs of HR (upper picture) and HS (lower picture) research areas.

Appendix 3: Description of topographic and geomorphology parameters at the soil study areas.

Site/ profile	Elevation m a.s.l.	Topography	Exposure	Slope %	Surface stoniness %	Surface rockiness %
HR	485	convex upper slope	N-W	22	3	0
HS 1	380	straight upper slope	S	17	90	0
HS 2	380	straight mid-slope	S	25	90	0
MN	300	foot slope	E	4	0	0
PC	800	straight mid-slope	S-W	11	0	90

Appendix 4: Description of ecological parameters and fire status at the soil study areas.

Site/profile	Dominant canopy species	Canopy cover %	Max. canopy height m	Fire return interval *	Erosion
HR	*D. tuberculatus, S. obtusa*	50	17	annually	severe
HS 1 upper slope	*S. obtusa, D. obtusifolius*	50	8	annually	moderate
HS 2 mid slope	*S. obtusa, D. obtusifolius*	50	8	annually	severe
MN	*S. obtusa, Xylia xylocarpa*	80	25	between 2-5 years	no-slight
PC	*S. obtusa, Xylia xylocarpa*	50	14	annually	severe

*Fire return interval was estimated based on indicator shrub species, fire signs at stem foot level and local information.

Appendix 5: Description of parent materials, soil-types and horizon classifications at the soil study areas.

Profile	Parent material	Soiltype (FAO)	Horizon name/depth cm				
HR	Quarternary fluvial sediments over paleozoic quartz mica shist	Rudi-Haplic Alisol	Ah 0-7	BE 7-20	2Bt 20-36	3Bts 36-49	C >49
HS upper slope	Quaternary cover over palaeozoic quartz-rich sandstones	Rudi-Luvic Arenosol	Ah 0-6	EB 6-26	CB 26-41	CBt 41-52	Cm >52
HS mid. slope	Palaeozoic quartz-rich sandstones	Rudi-Luvic Arenosol	Ah 0-6	EB 6-22	CB 22-50	CB 50-81	2 Cm >81
MN	Quaternary cover over palaeozioc quartz-rich sandstones	Rudi-Luvic Arenosol	Ah 0-10	EB 10-25	CB 25-40	Cm >40	
PC	Lower ordovicium limestone	Cromi-Calceric Cambisol	Ah 0-10	Bh 10-18	Cm 18-50	Cm >50	

Appendix 6: Non tree species cover and abundance at each site study sampling plot (plots size 78.5 m²). For species cover and abundance scale compare Tab. 2.2.

Non tree species	**HR 1**	**HR 2**	**HR 3**	**HS 1**	**HS 2**	**HS 3**	**MN 1**	**MN 2**	**MN 3**	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Abrus precatorius L.	r			r	s	s							
Aganosma marginata (Roxb.) G. Don			s										
Antidesma acidum Retz.								s					
Apluda mutica L.							2b						
Aporusa dioica (Roxb.) M.-A.							s	s					
Ardisia crenata Sims var. crenata									s				
Bambusa tulda Roxb.							2a	1					
Bambusa vulgaris Schrad. ex Wend. var. vulgaris							2a	2b					
Barleria cristata L.					s	s	s	s					
Blumea lacera (Burm. f.) DC.		s						r		r			
Blumea napifolia DC.								s	r				
Borreria brachystema (R. Br. ex Bth.) Valet.				s	s					2b			
Breynia fruticosa (L.) Hk. f.		r											
Bridelia affinis Craib										s			
Capillipedium parviflorum (R. Br.) Stapf						r							
Capparis pyrifolia Lmk.										r	r		
Catunaregam spathulifolia Tirv.		r		s			s		s	1			
Celastrus paniculatus Willd.										2b	s	r	
Ceriscoides sessiliflora (Kurz) Tirv.		r									s	s	
Cissampelos pareira L. var. Hirsuta (B.-H. ex DC) Forman								r					
Clausena excavata Burm. f.									r				
Commelina diffusa Burm. f.							r		s				
Costus speciosus (Koeh.) J.E. Sm.							r	r	r				
Craibiodendron stellatum (Pierre) W.W. Sm.	r	1	s	s		r							
Cratoxylum formosum (Jack) Dyer ssp. Pruniflorum (Kurz) Gog.			r				r	r					
Crotalaria alata D. Don		s	r		s	s			r				
Crotalaria albida Hey. ex Roth				s									
Crotalaria kurzii Baker ex Kurz						s							
Curcuma zedoaria (Berg.) Rosc.										r			r
Cyperus diffusus Vahl var. Diffusus							s	s	s				
Cyrtococcum accrescens (Trin.) Stapf										2b			
Desmodium heterocarpon (L.) DC. ssp. heterocarpon var. strigosum Mee.						r	s			2b			
Desmodium oblongum Wall. ex Bth.					s								
Desmodium triangulare (Retz.) Merr.										2a	2a	3a	3
Digitaria setigera Roth ex Roem. & Schult. var. setigera										2b	2b		
Dunbaria bella Prain				s			r	r					

Non tree species	**HR 1**	**HR 2**	**HR 3**	**HS 1**	**HS 2**	**HS 3**	**MN 1**	**MN 2**	**MN 3**	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Ellipelopsis cherrevensis (Pierre ex Fin. & Gagnep.) R.E. Fr.		r	s	s	s	s							
Eulalia leschenaultiana (Decne.) Ohwi	3b	3b	1	1	2b	s	r		s				
Eulalia speciosa (Deb.) O.K. var. speciosa							s	s	r				
Eupatorium odoratum L.								r	r				
Fimbristylis dichotoma (L.) Vahl ssp. dichotoma					r								
Flemingia sootepensis Craib	s	s	s	s	s	s	r	s					
Gardenia obtusifolia Roxb. ex Kurz		r	s	r		r		r	r	s			
Grewia abutilifolia Vent. ex Juss.	r	r	r	r				r		s			
Grewia hirsuta Vahl										2b	2a	2b	
Grona grahamii Bth.	s	s	s			s			r				
Gymnema griffithii Craib					r								
Hedyotis pinifolia Wall. Ex G. Don						s							
Hedyotis tenelliflora Bl. var. kerrii (Craib) Fuku.					r		s		s	2a		r	
Helicteres elongata Wall. ex Boj.			r	s		s							
Hemigraphis glaucescens (Nees) Cl.	3b	2a		s	s					2a	3a	4	1
Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	s	1	s	1	1					2a	2a		
Heteropogon triticeus (R. Br.) Stapf									r				
Hiptage benghalensis (L.) Kurz ssp. benghalensis										r			
Indigofera cassioides Rottl. ex DC.	2b	1	s							2b			
Indigofera linnaei Ali					s								
Inula cappa (Ham. ex D. Don) DC. forma cappa	s												
Inula indica L.		s		s	s	s				r			
Jasminum adenophyllum Wall. ex Cl.										s		s	
Justicia procumbens L.									s				
Knoxia brachycarpa R. Br. ex HK. f.								s	s	r			
Leea indica (Burm. f.) Merr.	s	r					s	s	r				
Lygodium flexuosum (L.) Sw.				2a	2a	2b							
Memecylon edule Roxb. var. Edule			r	r									
Memecylon scutellatum (Lour.) Naud.										r			
Micromelum minutum (Forst. f.) Wight & Arn.	r						s	s					
Millettia extensa (Bth.) Bth. ex Baker										r			
Millettia pachycarpa Bth.												r	
Mimosa diplotricha C. Wright ex Sauv. var. diplotricha					1	2b				s			
Mitracarpus villosus (Sw.) DC.										s			
Mnesithea granularis (L.) Kon. & Sos.							s			2a	2a		
Mnesithea striata (Nees ex Steud.) Kon. & Sos.										r			

Non tree species	HR 1	HR 2	HR 3	HS 1	HS 2	HS 3	MN 1	MN 2	MN 3	PC 1	PC 2	PC 3	PC 4
Murdania loureirii (Hance) Rao & Kam.			r										
Olax scandens Roxb.								1	s				
Ophiopogon brevipes Craib		r	r					r					
Oplismenus compositus (L.) P. Beauv.									r				
Oryza meyeriana (Zoll. & Mor.) Baill. var. granulata (Watt) Duist.									r	2b			
Paederia pallida Craib										2b	2b		
Paederia wallichii Hk. f.	s												
Panicum brevifolium L.									s				
Panicum notatum Retz.							r						
Pavetta fruticosa Craib									r				r
Pennisetum pedicellatum Trin.			r							2a	2a	2b	
Phaulopsis dorsiflora (Retz.) Sant.								r					
Phoenix humilis Roy. var. humilis	2a									s	r	r	1
Polytoca digitata (L. f.) Druce				1	2b					s			
Premna herbacea Roxb.				r			s						
Pueraria stricta Kurz										s		2b	
Sauropus quadrangularis (Willd.) M.-A. var. Puberlus Kurz											r		
Schizachyrium brevifolium (Sw.) Nees										2b			
Schizachyrium sanguineum (Retz.) Alst.				s			s	s	s				
Scleria levis Retz.				r			s		s	2b	2b	2b	2b
Scleria lithosperma (L.) SW. Var. Lithossperma					r								
Selaginella ostenfeldii Hier.	1	1	1	s	s	s			s	s	2a	2b	
Sericocalyx schomburgkii (Craib) Brem.									s				
Smilax lanceifoia Roxb.													1
Smilax ovalifolia Roxb.							s	s	s				
Smilax verticalis Gagnep.				r									
Spatholobus parviflorus (Roxb.) O.K.									r				
Stemona kerrii Craib							r	s	s				
Streptocaulon juventas (Lour.) Merr.			s										
Telosma pallida (Roxb.) Craib										r			
Themeda triandra Forssk.										2b	2a	2b	
Thyrostachys siamensis (Kurz ex Munro) Gamb.							r						4
Turraea pubescens Hell.							s	s					
Vangueria (Meyna) spinosa Roxb.							r	s	s				1
Vernonia squarrosa (D. Don) Less. var. silhetensis				r	r								
Ziziphus rugosa Lmk. var. rugosa	1												

Appendix 7: Tree species cover and abundance at each site study sampling plot (plots size 78.5 m²). For species cover and abundance scale compare Tab. 2.2.

Tree species	**HR 1**	**HR 2**	**HR 3**	**HS 1**	**HS 2**	**HS 3**	**MN 1**	**MN 2**	**MN 3**	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Albizia lebbeck (L.) Bth.										r			1
Anneslea fragrans Wall.	2b	s	s				s						
Aporusa villosa (Lindl.) Baill.	1		s				s						s
Buchanania lanzan Spreng.	1	1		r	2b	s				s	s	s	1
Canarium subulatum Guill.	r	r	r				s		r				
Careya arborea Roxb.									r				
Casearia grewiifolia Vent. var. grewiifolia								r					
Croton robustus Kurz							1	s	s				
Dalbergia cana Grah. ex Bth. var. cana					r			r					
Dalbergia dongnaiensis Pierre							r						
Dalbergia fusca Pierre	s												r
Dipterocarpus obtusifolius Teijsm. ex Miq. var. Obtusifolius	s	s	1	2b	2b	1							
Dipterocarpus tuberculatus Roxb. var. tuberculatus	s	s	1		1								
Eugenia cumini (L.) Druce		r		r									
Ficus hispida L. f. var. hispida							s	r	r	s			
Flacourtia indica (Burm. f.) Merr.							r	s	r	s	r		2b
Gardenia sootepensis Hutch.								r	r	2b			
Grewia eriocarpa Juss.						r				2b			
Lagerstroemia macrocarpa Kurz var. macrocarpa									s				
Litsea glutinosa (Lour.) C.B. Rob. var. glutinosa							s	s	r	s			
Melientha suavis Pierre ssp. suavis										s		r	
Mitragyna hirsuta Hav.							r	r		2a			
Morinda tomentosa Hey. ex Roth		r									s		
Ochna integerrima (Lour.) Merr.	s	1	s		r	r							
Pavetta tomentosa Roxb. ex Sm.							r			2a			
Phyllanthus emblica L.			r										
Pterocarpus macrocarpus Kurz	s												
Quercus kerrii Craib var. Kerrii	r	s											r
Schleichera oleosa (Lour.) Oken										2b			

Tree species	**HR 1**	**HR 2**	**HR 3**	**HS 1**	**HS 2**	**HS 3**	**MN 1**	**MN 2**	**MN 3**	**PC 1**	**PC 2**	**PC 3**	**PC 4**
Shorea obtusa Wall. ex Bl.	1	1	2a	2b	2b	r			s	r			1
Shorea siamensis Miq. var. Siamensis				r		s			s	s			
Siphonodon celastrineus Griff.										r			
Stereospermum neuranthum Kurz									r		r		
Strychnos nux-vomica L.	s									s			
Symplocos racemosa Roxb.						r							
Tectona grandis L. f.								r					
Terminalia alata Hey. ex Roth							s	s	s		2b	s	1
Terminalia chebula Retz. var. chebula										2b			
Terminalia mucronata Craib & Hutch.							s	1	1				
Tristaniopsis burmanica (Griff.) Wils. & Wat.				r									
Uraria campanulata (Wall. ex Bth.) Gagnep.							s	s					
Vangueria (Meyna) pubescens Kurz							1	s	s				
Vitex canescens Kurz									r	r			
Vitex limoniifolia Wall. ex Kurz							r	s	s				1
Walsura trichostemon Miq.													
Xantolis boniana (Dub.) Royen						r	s	s	s				
Xylia xylocarpa (Roxb.) Taub. var. kerrii							s		s				r

Appendix 8: Species list and their respective codes.

Species	Code	Family
Anneslea fragrans Wall.	ANNEFRAG	*Theaceae*
Antidesma acidum Retz.	ANTIACID	*Euphorbiaceae*
Bridelia pubescens Kurz	BRIDPUBE	*Euphorbiaceae*
Buchanania glabra Wall. ex Hk. f.	BUCHGLAB	*Anacardiaceae*
Buchanania lanzan Spreng.	BUCHLANZ	*Anacardiaceae*
Cananga latifolia (Hk. f. & Th.) Fin. & Gagnep.	CANALATI	*Annonaceae*
Canarium subulatum Guill.	CANASUBU	*Burseraceae*
Casearia grewiifolia Vent. var. grewiifolia	CASEGREW	*Flacourtiaceae*
Catunaregam tometosa (Bl. ex DC.) Tirv.	CATUTOME	*Rubiaceae*
Chukrasia tabularis A. Juss.	CHUKTABU	*Meliaceae*
Craibiodendron stellatum (Pierre) W.W. Sm.	CRAISTEL	*Ericaceae*
Cratoxylum formosum (Jack) Dyer ssp. Pruniflorum (Kurz) Gog.	CRATFORM	*Hypericaceae*
Dalbergia fusca Pierre	DALBFUSC	*Leguminosae*
Dillenia parviflora Griff. var. Kerrii	DILLPARV	*Dilleniaceae*
Diospyros ehretioides Wall. ex G. Don	DIOSEHRE	*Ebenaceae*
Dipterocarpus obtusifolius Teijsm. ex Miq. var. Obtusifolius	DIPTOBTU	*Dipterocarpaceae*
Dipterocarpus tuberculatus Roxb. var. tuberculatus	DIPTTUBE	*Dipterocarpaceae*
Eugenia cumini (L.) Druce	EUGECUMI	*Myrtaceae*
Garcinia cowa Roxb.	GARCCOWA	*Guttiferae*
Gardenia obtusifolia Roxb. ex Kurz	GARDOBTU	*Rubiaceae*
Gardenia sootepensis Hutch.	GARDSOOT	*Rubiaceae*
Gluta usitata (Wall.) Hou	GLUTUSIT	*Anacardiaceae*
Grewia eriocarpa Juss.	GREWERIO	*Tiliaceae*
Haldina cordifolia (Roxb.) Rids.	HALDCORD	*Rubiaceae*
Irvingia malayana Oliv. ex Benn.	IRVIMALA	*Irvingiaceae*
Lophopetalum wallichii Kurz	LOPHWALL	*Celastraceae*
Memecylon scutellatum (Lour.) Naud.	MEMESCUT	*Melastomataceae*
Mitragyna hirsuta Hav.	MITRHIRS	*Rubiaceae*
Morinda tomentosa Hey. ex Roth	MORITOME	*Rubiaceae*
Ochna integerrima (Lour.) Merr.	OCHNINTE	*Ochnaceae*
Phyllanthus emblica L.	PHYLEMBL	*Euphorbiaceae*
Pterocarpus macrocarpus Kurz	PTERMACR	*Sterculiaceae*
Quercus kerrii Craib var. Kerrii	QUERKERR	*Fagaceae*
Shorea obtusa Wall. ex Bl.	SHOROBTU	*Dipterocarpaceae*
Shorea siamensis Miq. var. Siamensis	SHORSIAM	*Dipterocarpaceae*
Spondias pinnata (L. f.) Kurz	SPONPINN	*Anacardiaceae*
Stereospermum neuranthum Kurz	STERNEUR	*Bignoniaceae*
Strychnos nux-vomica L.	STRCNUX-	*Loganiacae*
Symplocos racemosa Roxb.	SYMPRACE	*Symplocaceae*
Terminalia alata Hey. ex Roth	TERMALAT	*Combretaceae*

Species	Code	Family
Terminalia chebula Retz. var. chebula	TERMCHEB	*Combretaceae*
Tristaniopsis burmanica (Griff.) Wils. & Wat.	TRISBURM	*Myrtaceae*
Vitex limoniifolia Wall. ex Kurz	VITELIMO	*Verbenaceae*
Walsura trichostemon Miq.	WALSTRIC	*Meliaceae*
Ziziphus rugosa Lmk. var. rugosa	ZIZIRUGO	*Rhamnaceae*

Species codes used according to CMU HERBARIUM DATABASE (2000).

Appendix 9: Relative abundance of tree species as studied during stand status assessment at HR and HS.

Species	Adult trees		Saplings		Seedlings	
	HR	HS	HR	HS	HR	HS
	%					
ANNEFRAG	0.39	0.02	0.35	0.24	0.81	0.29
ANTIACID	0.00	0.00	0.00	0.00	0.12	0.00
BRIDPUBE	0.45	0.05	0.71	0.00	0.12	0.00
BUCHGLAB	0.12	0.39	0.00	0.24	0.81	1.45
BUCHLANZ	0.00	0.32	0.00	0.00	0.00	0.72
CANALATI	3.25	1.93	1.59	0.24	1.16	1.45
CANASUBU	5.16	2.55	5.12	0.73	1.62	1.30
CASEGREW	0.09	0.00	0.00	0.00	0.12	0.00
CATUTOME	0.09	0.30	0.88	5.37	3.13	1.73
CHUKCORD	0.15	0.00	0.00	0.00	0.00	0.00
CRAISTEL	0.18	0.02	0.35	0.00	0.58	0.00
CRATFORM	0.00	0.00	0.35	0.73	2.09	16.18
DALBFUSC	0.78	0.73	2.83	0.00	8.46	1.16
DILLPARV	0.27	0.18	0.18	0.24	1.74	2.75
DIOSEHRE	0.15	0.05	0.00	0.00	0.23	0.14
DIPTOBTU	14.32	38.49	10.25	21.46	5.68	15.75
DIPTTUBE	46.60	2.07	23.32	0.00	22.94	0.00
EUGECUMI	0.27	0.44	0.18	1.46	0.23	0.00
GARCCOWA	0.09	0.18	0.53	0.00	2.67	2.60
GARDERYT	0.03	0.00	0.00	0.00	0.00	0.00
GARDOBTU	0.15	0.07	1.24	1.46	2.09	1.01
GLUTUSIT	2.48	14.55	0.35	11.46	4.29	7.08
GREWERIO	0.00	0.02	0.00	0.00	0.00	0.00
HALDCORD	0.00	0.00	0.18	0.00	0.23	0.00
IRVIMALA	0.12	0.28	0.00	0.24	0.00	0.14
LOPHWALL	0.00	0.00	0.00	0.00	0.58	0.14
MEMESCUT	0.00	0.16	0.00	0.73	0.00	2.60
MITRHIRS	0.00	0.09	0.00	0.73	0.00	0.43
MORITOME	0.09	0.07	0.00	0.00	0.00	0.00
OCHNINTE	0.03	0.39	0.00	1.95	9.85	2.31
PHYLEMBL	0.00	0.00	0.00	0.73	0.00	0.58
PTERMACR	0.39	0.02	1.24	0.49	0.00	0.14
QUERKERR	0.51	0.07	1.59	0.00	1.51	0.29
SHOROBTU	21.57	27.79	44.52	40.00	20.97	28.32
SHORSIAM	0.06	8.08	0.88	10.73	0.00	4.62
SPONSPINN	0.06	0.00	0.00	0.00	0.00	0.00
STERNEUR	0.33	0.25	0.53	0.00	2.55	1.01

Species	Adult trees		Saplings		Seedlings	
	HR	HS	HR	HS	HR	HS
			%			
STRCNUXV	0.42	0.05	0.71	0.00	0.58	0.00
SYMPRACE	0.03	0.07	0.00	0.00	0.00	0.00
TERMALAT	0.03	0.00	0.18	0.00	0.00	0.00
TERMCHEB	0.42	0.09	0.35	0.00	0.46	0.14
TRISBURM	0.42	0.14	1.24	0.73	3.01	5.64
VITELIMO	0.42	0.07	0.35	0.00	1.39	0.00
WALSTRIC	0.06	0.00	0.00	0.00	0.00	0.00
ZIZIRUGO	0.06	0.02	0.00	0.00	0.00	0.00

Appendix 10: Definition of sustainable forest management:

The totality of those direct and indirect measures of utilisation, cultivation and protection in a forest ecosystem which secure the lasting existence and natural development of the forest, the adequacy of its functions and the preservation of its species richness and diversity of life forms on which the fulfilment of its economic, ecological, social and spiritual functions depends (BRÜNIG, 1998).